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PICATINGLY GENERAL
SCIENTIFIC AND TECHNICAL INFORMATION BRANCH

JOURNAL
OF THE
ROYAL NAVAL
SCIENTIFIC SERVICE



20090126 062

Vol. 29



SEPTEMBER 1974



No. 5

RESTRICTED

R100,157
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SIR FREDERICK BRUNDRETT, K.C.B., K.B.E. AN APPRECIATION

SIR Frederick Brundrett, K.C.B., K.B.E., who died recently at the age of 79 served as Chief of the Royal Naval Scientific Service from 1946 to 1950, in succession to Sir Charles S. Wright, K.C.B., O.B.E., M.C. Four years later he succeeded Sir John Cockcroft as Scientific Adviser to the Ministry of Defence and Chairman of the Defence Research Policy Committee. Sir Frederick was born on November 25, 1894 and educated at Rossall School and Sydney Sussex College, Cambridge, where he became a Wrangler. He joined the then Wireless Branch of R.N.V.R. in 1916 and was later engaged in research work on underwater communications with submarines. When demobilised in 1919 he joined the Scientific Staff of the Admiralty at the Old Signals School where he remained until 1937. He was then promoted to Principal Scientific Officer and transferred to the Headquarters of the Chief of the Royal Naval Scientific Research in London, being promoted to Superintending Scientist in 1939, Assistant Director of Scientific Research in 1940, Deputy Director of Scientific Research in 1942 and as previously mentioned Chief of the Royal Naval Scientific Service in 1946.

During the Second World War he was closely involved in the recruitment of Scientists and Scientific workers in the Government Service but his principal scientific work was concerned with the development of short wave radio in which he had played a leading part in the period between the two world wars. The thing most remembered of Sir Frederick as Scientific Adviser to the Minister of Defence and earlier as Deputy to Sir Henry Tizard and Sir John Cockcroft was the extent to which he gained and held the confidence of various Chiefs of Staff in the days when there was no united Ministry of Defence.

He was not only trusted in his handling of Defence R & D programmes but his down to earth advice and help in resolving many more directly military problems and arguments were always welcomed. On retirement from the post of Scientific Adviser in 1959 he was appointed Chairman of the Air Traffic Control Board and became a Civil Service Commissioner from 1960 to 1967. From 1960 onwards for six years he was Chairman of the Naval Aircraft Research Committee, Aeronautical Research Council.

Although a very busy man throughout his life he did in his later years find time to become a very successful farmer and brought his abilities to bear upon many aspects of agriculture. He was for some years Chairman of the Red and White Friesian Cattle Society, a position of which he was extremely proud.

In a letter recently received, Sir Charles S. Wright, who was the war-time Director of Scientific Research, Admiralty, and the first C.R.N.S.S., states:

"It must have been during 1920 when I first met Brundrett at the Signal School. He was not in uniform at that time but was employed in the office of the Captain of the Signal School. He made an immediate impression upon me. This was during the early days of the research department when we were a very small body under F. E. Smith as a Director of Scientific Research and when we had as a Department few friends in the Admiralty and had to step very delicately (like Agag) in order not to tread upon other departmental toes. It was not until Captain Im Thurn, the then Director of the Signal Department at the Admiralty, made the suggestion to F. E. Smith (later Sir Frank) that our efforts to achieve an organisation (which amongst other things would improve our salary scales) should be enlarged to include the scientific and experimental staffs then employed at the Signal School, the Anti-submarine and the Mining Establishments. This was approved by the Treasury in due course and I then spent five or six years in efforts to persuade successive Captains of the Signal School that the right place for Brundrett with his special talents was at our Headquarters in the Admiralty. This I succeeded in doing in 1937.

In his new position the department took on a new lease of life and Brundrett rapidly showed his organising ability. He took over more and more of the administrative details

and well it was that he did so, before the Second World War was upon us and we had to absorb large numbers of Scientists, Professors, Ph.Ds., M.As. and highly qualified Engineers and fit them into our organisation.

His reputation had by this time reached well beyond the Admiralty and our opposite numbers readily agreed to leave to C. P. Snow of Cambridge University and to Brundrett, the distribution of available manpower between the Services. All this involved great tact and persuasive ability. When war finally broke out the staff were swollen by Technicians and Scientists driven by the enemy from their homes. For example, the Norwegians to help us in our anti-submarine experimental work and the Polish contingent who worked with us on infra-red research for all the Services at the Admiralty Research Laboratory. At this time his experience at the Signal School was specially valuable.

In the years before the war we often used to discuss the major issues and in particular the impossibility of persuading the Treasury that we should be organised for maximum efficiency in war-time rather than for maximum efficiency in days of peace and also the need for examining at intervals the ideas previously examined and turned down because increasing knowledge and better techniques might then make them possible, a small Parliamentary Committee had the face to interview Brundrett and myself after the war had ended to ask for the reason why we had not progressed further in our anti-submarine experiments before the war. The answer was all too clear: "because Parliament and the Treasury were too stingy with their financial help." This was at a time when neither the Americans nor the French had done any serious work to compare with our Asdic equipment and techniques.

Brundrett it was, who as chief architect of our post-war organisation, headed by a Chief of the Royal Naval Scientific Service, actually managed to persuade the Treasury to approve a number of vacant posts to be filled in the future and persuaded it (or is it them?) that the normal Civil Service routine which rated rank (and salary) in terms of the number of workers for whose work an individual was responsible, was not wholly suitable to a Scientific Service which must rely in some degree upon individual skill in research or engineering.

The R.N.S.S. owes a great deal to his care for personnel but it would be wrong to assume that his efforts were wholly devoted to the administration side. He took an important part in the development of the 10 centimetre magnetron. Vannevar Bush, Head of the U.S. Civilian Research and War Development activities has said that the 10 centimetre cavity magnetron was the most important result of reverse lease lend during the war.

Our efforts towards the development of the magnetron with its very great output (flypower to elephant power) started before the war. I think it was a paper by Dempsey in the Journal of the Franklyn Institute which started me off and led to an arrangement with the Treasury for the first development contract with the General Electric Company (British) and after the war had started, with Birmingham University (Sir Raymond Priestley the then Vice Chancellor) and Professor Oliphant who were both very strongly in favour and most helpful. In due course our hopes for various powerful transmitters was achieved as the result of Randall and Boot both working in Oliphant's laboratory. All this effort and the corresponding work on suitable receivers for RDF (Radar) was directed by our valve development committee (CVD) under DSR Admiralty. With this high frequency system radar could be used on ships and on aircraft and by army units to measure the range and accurate bearing thereby converting the old radar system into a real weapon of offence. Naturally representatives of the Air and Army Research Directors asked to be represented on a new interservice CVD Committee with DSR Admiralty as Chairman of the Working Party, under Professor Whiddington, within DSR's Admiralty Organisation. DSR was at first reluctant to accept this proposal but was persuaded by Brundrett that this would be in the best interest of all the Fighting Services. Brundrett never failed to speak out on such occasions and had a very valuable quality in those days of being a member of multitudinous committees with the advantage of being able to listen to all sides and to come up with suggestions which were acceptable to all. He was an excellent fighter and one who did not lose his temper in an argument. On the other hand when he felt strongly about any matter, compromise did not come readily to him and I think he may have frightened some of the many "new boys" who joined the staff by his incisive manner. He could however suffer fools quite gladly when this seemed necessary. In my opinion he was the perfect Deputy to his Director. His was a complex character and his virtues were not fully apparent at first sight. I take much credit to myself that I spotted my man in what seemed likely to become a dead end job at the Signal School and got him away from his farm at Emsworth thereby opening up to him the opportunity of his subsequent career in more exalted Government circles. I doubt if it happens very often that one is able to retire with absolute assurance that one's department will be in better hands than one's own."

Sir Frederick Brundrett made a great but characteristically unspectacular contribution to the advance of military technology and the provision of the most advanced equipment for the armed forces at a time when it was most needed. He was directly responsible for the formation of the Royal Naval Scientific Service and its functions. The success and achievements of the R.N.S.S. over the past 30 years owes much to the foresight and vigour of Sir Frederick in laying such solid foundations.

THE CORROSION OF COUPLES OF CARBON FIBRE REINFORCED PLASTICS AND METALS

A. R. G. Brown, M.Sc., A.I.M.

Royal Aircraft Establishment

Introduction Carbon fibre reinforced plastics (CFRP) can be produced with a wide range of useful mechanical properties. Their use in a wide variety of structures which could be operated in many different environmental conditions can be justified on structural efficiency grounds. In many of the possible applications CFRP could be used to strengthen or stiffen conventional metal components⁽¹⁾, in which cases the CFRP would be in intimate contact with the metal; in cases where components made wholly of CFRP are suggested these components will usually be attached to metallic structures using attachment fixtures which themselves would probably be of metal. A further proposed use for CFRP type materials is in bearings, and here again there would be close contact with metals.

It has long been known that, in contact with common metals, graphite can act as a noble electrode and greatly accelerate corrosion⁽²⁾. However, it was uncertain whether the matrix resin of CFRP would form an efficient insulating layer around the fibres and thus eliminate the danger of galvanic attack.

Studies were therefore undertaken to characterise some CFRP to metal couples electrochemically, and also to examine the extent of the local aggravated corrosion at CFRP to metal contacts. As the main interest at RAE is in aircraft structural materials, work has been concentrated on CFRP—aluminium alloy couples, though other metal components have been looked at. Neutral aqueous salt solution has been used as corrodent in accelerated tests both because it is a convenient medium and also because it is known that even aircraft

bilge fluids usually contain sodium chloride and are essentially neutral⁽³⁾. As the results of accelerated corrosion tests are always open to question, long term natural exposure tests were also carried out.

This article summarizes information acquired over the last five years. Consequently the techniques of bonding and protection were those current in 1968; they should not be taken as necessarily typical of current practice.

Experimental

Materials

The metals used are listed in Table 1. The aluminium alloys represent the main types of wrought alloy used in aircraft construction. All of the metals except the titanium alloy were produced in the United Kingdom. In all cases the specimens were cut from commercial sheets. Unless otherwise stated the CFRP was cut from 3-ply laminate sheets 300 mm. square \times 3 mm. thick containing about 50 vol. % Type I untreated carbon fibre in a matrix of the epoxy resin LY558 cured with 5% of a proprietary boron trifluoride.

Electrochemical Measurements

Reaction potential measurements were made against commercial saturated calomel reference electrodes (SCE). Test samples about 80 mm. \times 10 mm. were partially immersed in unstirred neutral 5% aqueous NaCl solution, made up from laboratory grade NaCl and distilled water. The ends of the test pieces were drilled and they were supported by bolting them to ebonite rods using nylon bolts and washers.

TABLE 1.
Schedule of the Metals Used

<i>Alloy</i>	<i>Nominal Composition (wt%)</i>	<i>Condition</i>
L 16	Al 99 min	Half hard
L 71	Cu 4.4, Mg 0.7, Si 0.7, Mn 0.6, Al balance.	Solution treated and artificially aged
L 73	Cu 4.4, Mg 0.5, Si 0.7, Mn 0.8, Al balance	Clad with 99.7% Al. Solution treated and artificially aged.
DTD 687 A	Cu <1.5, Mg. 2.5, Zn 5.5, Al balance	Solution treated and artificially aged. Cladding machined off.
DTD 5070 A	Cu 2.5, Mg 1.5, Ni 1.2, Fe 1.0, Al balance	Solution treated and artificially aged. Clad Al-1Zn
S 510	C 0.17 to 0.25, Si 0.1 to 0.35, Mn 0.44 to 0.8, Fe balance.	Annealed
S 521	Cr 18, Ni 8, Fe balance.	Annealed
FV 520 S	C .05, Mn 1.3, Cr 15.5, Ni 5.5, Cu 1.8, Mo 1.5, Ti 0.1, Fe balance.	Solution treated and aged.
Ti-6Al-4V	Al 6, V 4, Ti balance.	Solution treated and aged

Polarization experiments were conducted in the cell illustrated in Fig. 1. The metal and CFRP samples were held in stainless steel clamps supported by Pt-3% Rh wires. Polarization was effected either by joining the metal and CFRP electrodes through a known resistance, or using a potentiostat to hold the CFRP at a given potential. In both cases the cell currents and potentials were read 30 minutes after rapid change of conditions had ceased. The cell was operated in a thermostatically controlled bath.

Preparation of CFRP—Metal Couples

The bolted couples were made by bolting 50 × 25 mm. coupons of CFRP in the centre of 100 × 75 mm. metal plates. Initially cadmium plated steel bolts were used but in later work aluminium alloy, titanium alloy and stainless steel bolts were used as appropriate with no effect on the results. One series of bolted couples was made up dry, a second with the mating surfaces of the joints coated before assembly with chromated jointing compound conforming to DTD369A. Excess compound was used to fill any crevices, and was allowed to set for one week before the specimens were exposed.

The adhesive-bonded couples were made with EC2216 adhesive. No special precautions were

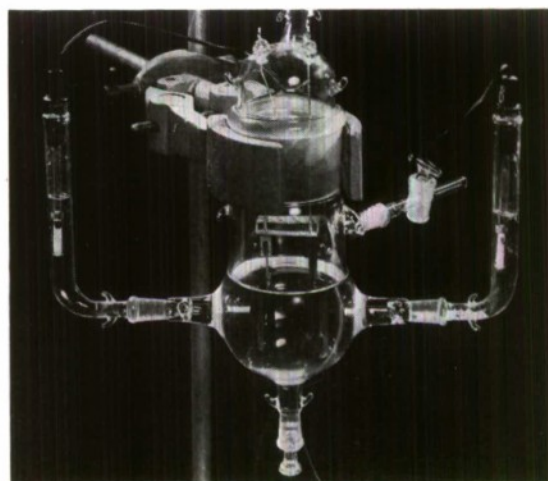


FIG. 1. The cell used for polarization measurements.

taken in making the joints; thick glue lines were used to ensure that the CFRP was electrically insulated from the metal.

Both bolted and bonded couples were made with Al alloys using as-received sheet, chromic acid anodized sheet (to DEF STAN 03 - 2/1 and DEF 151) and sheet given an Alocrom

METAL PRE-TREATMENT	NONE			ANODIZED			ALOCROM 1200			ANODIZE + PAINT			ALOCROM 1200 + PAINT		
	None	Bolting Dry Assem- bly	Adhe- sive Bonded	None	Bolting Dry Assem- bly	Adhe- sive Bonded	None	Bolting Dry Assem- bly	Adhe- sive Bonded	None	Bolting Dry Assem- bly	Adhe- sive Bonded	None	Bolting Dry Assem- bly	Adhe- sive Bonded
L 16															
General Corrosion	1	2*	1	1	1*	1	1	1	1	0	1*	0	0	1*	0
Pitting at edges of CFRP	-	5*	0	-	5*	0	-	5	0	-	3*	0	-	2*	0
Attack under CFRP	-	4*	0	-	5*	0	-	3	0	-	3*	0	-	2*	0
L 73															
General Corrosion	1	2	1	1	1	1	1	1	1	0	1*	0	0	1*	0
Pitting at edges of CFRP	-	3	0	-	3	0	-	4	0	-	1*	0	-	3*	0
Attack under CFRP	-	4	0	-	3	0	-	4	0	-	2*	0	-	2*	0
DTD 5070A															
General Corrosion	1	1*	1	1	1*	1	1	1*	1						
Pitting at edges of CFRP	-	4*	0	-	3*	0	-	4*	0						
Attack under CFRP	-	4*	0	-	3*	0	-	3*	0						
L 71															
General Corrosion				1-2	1-2*	1-2				0	0*	0	0	1*	0
Pitting at edges of CFRP				-	4*	0				-	0*	0	-	2*	0
Attack under CFRP				-	4*	0				-	4*	0	-	3*	1*
DTD 687A†															
General Corrosion				1-2	1-2*	1-2									
Pitting at edges of CFRP				-	3*	0									
Attack under CFRP				-	2*	0									

Corrosion key:

0—None 1—Very slight 2—Slight
 3—Moderate 4—Heavy 5—Very heavy

†—Cladding removed.

*—Specimen removed before standard exposure time completed

TABLE 2.

Results of Accelerated Testing of CFRP—Aluminium Alloy Couples.

Standard exposure time—42 days unpainted.

167 days painted.

METAL PRE-TREATMENT	NONE			ANODIZED			ALOCROM 1200			ANODIZE + PAINT			ALOCROM 1200 + PAINT		
	None	Bolted Dry	Wet Assem- bly	Adhe- sive Bonded	None	Bolted Dry	Wet Assem- bly	Adhe- sive Bonded	None	Bolted Dry	Wet Assem- bly	Adhe- sive Bonded	None	Bolted Dry	Wet Assem- bly
L 16															
General Corrosion	1	1	1	0-1	0-1	1	1	0-1	0	0-1	0-1	0	0	0	0
Pitting at edges of CFRP	-	3	2	0	-	1	0	0	-	2	0	0	-	2	1
Attack under CFRP	-	3	1	0	-	1	0	0	-	2	0	0	-	2	0
L 73															
General Corrosion	2	1	1	1-2	1-2	1	1	1-2	0	0-1	0-1	0	0	0	0
Pitting at edges of CFRP	-	4	2	0	-	2	2	0	-	1	0	0	-	2	0
Attack under CFRP	-	4	0	0	-	3	0	0	-	2	0	0	-	2	0
DTD 5070A															
General Corrosion	1	1	2	2	2	1-2	1	1	2	1	1	1-2			
Pitting at edges of CFRP	-	3	2	1	-	4	2	0	-	2	1	0			
Attack under CFRP	-	4	0	0	-	3	0	0	-	2	0	0			
L 71															
General Corrosion					2	2	1	2		0	0	0	0	0	0
Pitting at edges of CFRP					-	2	3	0		-	3	2	0	3	1
Attack under CFRP					-	4	0	0		-	4	0	0	3	0
DTD 687A†															
General Corrosion					2	2	2	2							
Pitting at edges of CFRP					-	4	3	0							
Attack under CFRP					-	4	0	0							

Corrosion ky:

0—None
 3—Moderate
 †—Cladding removed.

1—Very slight
 4—Heavy
 2—Slight
 5—Very heavy

TABLE 3.

Results of Exposure of CFRP—Aluminium Alloy
 Couples to an Industrial Environment for 4 Years.

METAL PRE-TREATMENT	NONE			ANODIZED			ALOCROM 1200			ANODIZE + PAINT			ALOCROM 1200 + PAINT		
	None	Bolted Dry	Adhe- sive Bonded	None	Bolted Dry	Adhe- sive Bonded	None	Bolted Dry	Adhe- sive Bonded	None	Bolted Dry	Adhe- sive Bonded	None	Bolted Dry	Adhe- sive Bonded
L 16															
General Corrosion	0-1	0-1	1		0-1	0-1		0-1	0-1	0	0-1	0	0	0-1	0
Pitting at edges of CFRP	-	1	0		3	2	0	2	0	-	2	1	-	2	0
Attack under CFRP	-	2	0		2	0	0	1	0	-	2	1	-	2	0
L 73															
General Corrosion	2	2	1		2	1	0	1	1	0	0-1	0	0	0-1	0
Pitting at edges of CFRP	-	2	1	0	3	2	0	2	1	0	1	1	-	1	0
Attack under CFRP	-	1	0	0	2	1	0	1	0	-	2	0	-	1	0
DTD 5070A															
General Corrosion	1	0-1	0-1		0-1	0-1	0-1	0-1	0-1	0-1	0-1	0	0	0-1	0
Pitting at edges of CFRP	-	2	1	0	2	2	0	3	1	0					
Attack under CFRP	-	3	0	0	2	0	0	2	0	0					
L 71															
General Corrosion				2	2	1	1			0	0-1	0-1	0	0-1	0
Pitting at edges of CFRP				-	2	2	1			-	1	2	1	2	0
Attack under CFRP				-	3	0	0			-	2	0	-	3	0
DTD 687A†															
General Corrosion				1	1	1	1								
Pitting at edges of CFRP				-	2	1	1								
Attack under CFRP				-	1	0	0								

Corrosion key:

3—Moderate
0—None1—Very slight
4—Heavy
5—Very heavy
2—Slight

†—Cladding removed.

TABLE 4.

Results of Exposure of CFRP—Aluminium Alloy
Couples to a Marine Environment for 4 Years.

1200 treatment. The plain carbon steel plates were cadmium plated and passivated (DEF STAN 03-4 and DEF 130) before making up the couples. The stainless steels and the titanium alloy were used "as-received".

A selection of couples was given an overall protective finish of one coat of chromate pigmented epoxy primer and one coat of epoxy top-coat (DTD 5555A).

Corrosion Testing

The accelerated testing was exposure to a fog of neutral aqueous NaCl at 35°C; the collection rate was 1.5 cm³ per hour over 80 cm² horizontal area. The tests on the unpainted aluminium alloy and mild steel couples were done in 3% NaCl fog maintained five days per week; at week-ends the spray was turned off, though the temperature was held at 35°C. To economise space the specimens were hung vertically. After the main series of tests was completed, further specimens were exposed in conformity with ASTM designation B117-64, Salt Spray (Fog) Testing, *i.e.* at 15° to vertical in a continuous 5% NaCl fog. No difference could be detected between replicates exposed under the two conditions. The tests were run for a nominal 42 days for unpainted specimens and 167 days for painted specimens. Badly corroded specimens were removed before completing the full exposure. Some tests on unpainted stainless steel and titanium alloy to CFRP couples were run for 167 days.

Specimens were also exposed to two natural environments, one marine and one industrial, on the East side of Hayling Island and on a roof at Euston Street, London, respectively. The specimens were supported on wooden racks at 45° to the vertical, using ceramic insulators to prevent contact with the wood.

Results

Electrochemical Measurements

Measurements of the reaction potential showed that for CFRP, this developed from an initial, very variable, value to an "equilibrium" value which was reached in about four days. The mean value for the CFRP used was +318 mV referred to SCE (sd 31.4 mV). CFRP made with treated Type II carbon fibres in the same matrix resin had an equilibrium potential of +302 mV (sd 11.2 mV).

The potentials of the metal specimens measured under the same conditions were:

	mV v SCE
Aluminium 4L16	-780
Aluminium alloy L71	-730
Cd (electroplate) on S510 steel	-730
Stainless steel (FV 520S)	+115
Stainless steel (S521)	+35
Ti-6Al-4V	+190

The polarization curve for the CFRP used, against L16 is shown in Fig. 2. Other types of CFRP show curves of the same general form, and the small changes in corrosion current observed are probably not highly significant. The polarization occurs almost entirely at the CFRP electrode. The effect of replacing the L16 by an aluminium alloy was small; the cathodic polarization curve was unaffected and the slight changes observed in the corrosion current resulted from displacement of the anodic polarization line.

The pH of the solution has little effect on the polarization behaviour over the range pH 3 to 11. The effect of NaCl concentration was also small over a wide range; at very low NaCl concentrations (0.001 M) the polarization behaviour was changing, but it was not established whether the presence of Cl⁻ is necessary for reaction to take place.

The effect of increasing temperature over the range 0-60°C is to increase the corrosion current 2-4% per °C rise in temperature. The results gave an activation energy of 18.8 kJ/mole, a low value consistent with a diffusion controlled mechanism.

A series of experiments using solutions with different concentrations of oxygen showed that corrosion current increases with increasing oxygen concentration. Plotting corrosion current against oxygen concentration a direct proportionality is indicated (Fig. 3).

Replacing the Cl⁻ anion by another halide or sulphate has little effect on polarization, nor does changing the cation from Na⁺ to K⁺. However, replacing chloride by chromate does give slightly higher corrosion currents while replacing Na⁺ by Fe³⁺ gives a very large increase (two orders of magnitude or more) in the corrosion current.

Corrosion of Couples between CFRP and Aluminium Alloys

The results of the accelerated corrosion tests are summarised in Table 2. None of the plain metal coupons exposed for 42 days showed serious corrosion, but when the metal was in electrical contact with CFRP there was severe corrosion, localised at the edges of the CFRP coupons. The L16 was most heavily

TABLE 5.
Corrosion of Painted and Unpainted Couples between CFRP and Cadmium Plated S510 Steel

<i>Type of CFRP to Metal Joint</i>	<i>Unpainted</i>				<i>Painted</i>			
	<i>None</i>	<i>Bolted Dry</i>	<i>Bolted Wet Asmby</i>	<i>Ad-hesive Bonded</i>	<i>None</i>	<i>Bolted Dry</i>	<i>Bolted Wet Asmby</i>	<i>Ad-hesive Bonded</i>
ACCELERATED TEST								
Duration (days)	47	14	14	42	167	167	167	167
General corrosion	1	2	2	2	0	1	1	1
Local attack at edges of CFRP	—	5	5	2	—	1	2	1
Attack under CFRP	—	4	0	0	—	3	1	1
INDUSTRIAL ENVIRONMENT								
Duration (days)	180	180	180	180	4y	4y	4y	4y
General corrosion	3	4	3	3	0	1	1	0
Local attack at edges of CFRP	—	4	4	3	—	0	0	0
Attack under CFRP	—	4	2	0	—	0	0	0
MARINE ENVIRONMENT								
Duration (days)	500	300	300	300	4y	4y	4y	4y
General corrosion	1	3	2	2	0	1	0	0
Local attack at edges of CFRP	—	4	4	5	—	2	2	1
Attack under CFRP	—	3	2	0	—	3	0	0

Corrosion key 0 — None 3 — Small rust patches
 1 — Cd attacked but no rusting 4 — Heavy rusting
 2 — Slight rust spots visible 5 — Extensive and heavy rusting

attacked (see Fig. 4) with the deepest pitting on the bolted, wet assembled test pieces (Fig. 5). The clad alloys L73 and DTD 5070A showed less marked pitting, while the de-clad DTD 687A and L71 showed the most extensive general corrosion. Thus L71 after 14 days' exposure as a bolted couple showed general corrosion similar to that of L73 (the same composition, but clad with aluminium) after 42 day exposure. Pre-treatment by anodizing or Alocrom 1200 does not stop the localised

attack. Thus, in the case of L16, untreated metal developed "trenches" round the CFRP whereas the pre-treated specimens developed pits which were individually deeper than the trench (Fig. 4). Wet assembly almost eliminates corrosion under CFRP bolted to aluminium alloys. A number of dry bolted couples between glass reinforced plastic and L16 were exposed; the metal showed no localised attack indicating that straightforward crevice corrosion is not involved.

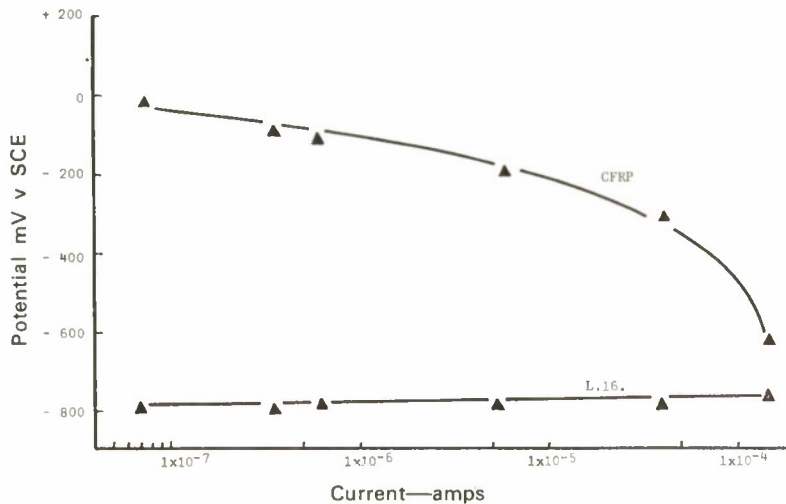


FIG. 2. Polarization curve for CFRP v Aluminium (L16) in Neutral Aqueous 5% NaCl

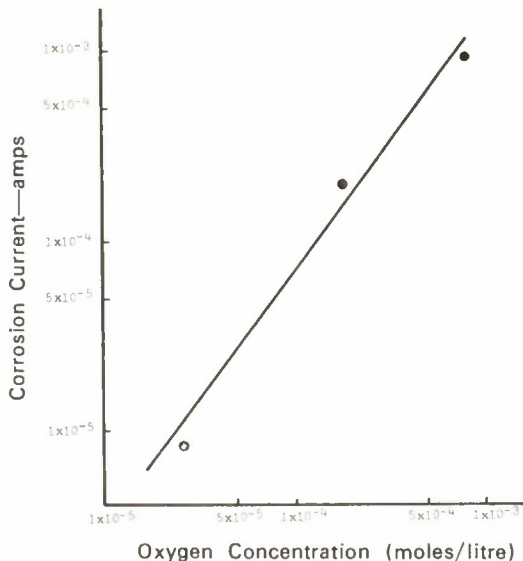


FIG. 3. The effect of oxygen concentration on corrosion rate (in neutral aqueous 5% NaCl)

The adhesive bonded specimens, with the CFRP electrically insulated from the metal showed no localised attack.

Painted plain metal specimens and adhesive bonded couples were virtually unattacked after 167 days' exposure. The painted bolted specimens showed localised attack concentrated around the edges of the CFRP coupons and in the case of L16 and L71 quite heavy pitting occurred (Fig. 6). In all cases where local attack occurred corrosion products could be seen on

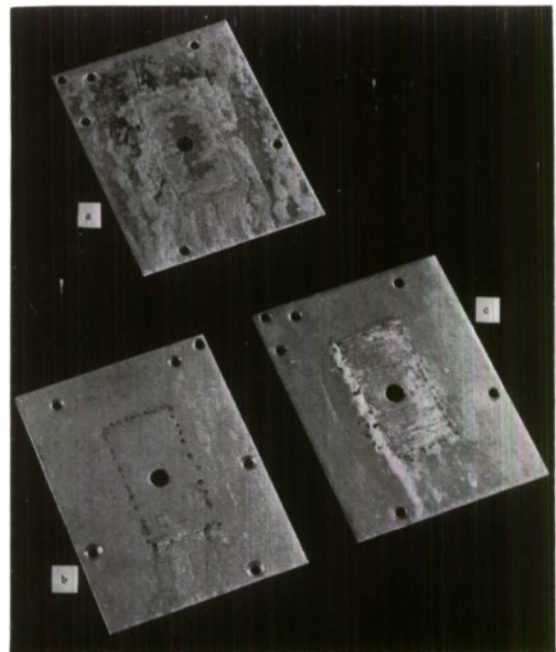


FIG. 4. L16 specimens after exposure to salt fog for 42 days.

(CFRP-L16 couples; bolted, wet assembled; CFRP removed and metal cleaned.)

- (a) L16 as received
- (b) L16 given Alocrom 1200 treatment
- (c) L16 anodized

the painted surface (Fig. 7). Wet assembly reduced the corrosion beneath the CFRP, though the pits at the edges of the CFRP appeared to be deeper than in the dry joints.

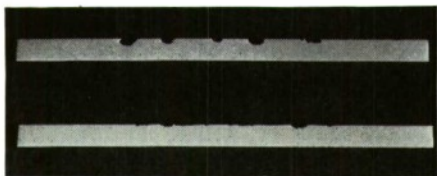


FIG. 5. Effect of wet assembly on pitting of L16. Section through metal at lower edge of CFRP. (CFRP-L 16 couples; Alocrom 1200 pre-treated; exposed to salt fog.)

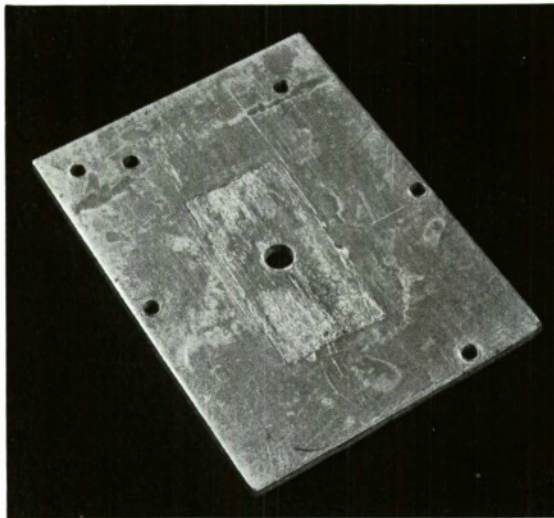


FIG. 6. Painted L16 specimen after exposure to salt fog for 87 days. (CFRP-L 16 couple; bolted, dry assembled; paint stripped and metal cleaned.)

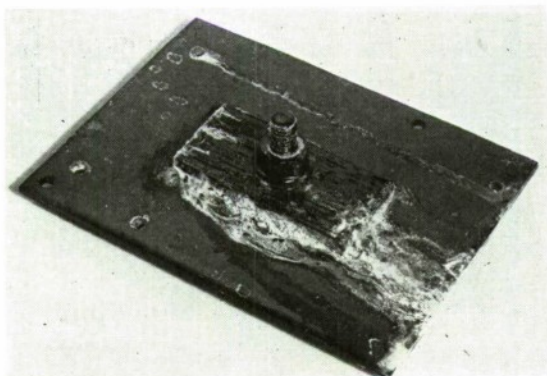


FIG. 7. Painted CFRP-L16 dry bolted couple after exposure to salt fog for 42 days.

The results of the natural exposure trials are summarised in Tables 3 and 4 for the industrial and marine environments respectively. Again the adhesive bonded specimens showed no signs of localised or accelerated

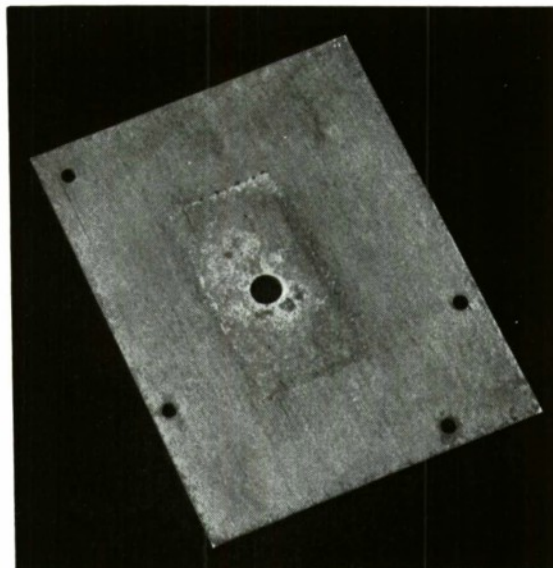


FIG. 8. Painted L71 specimen after exposure to industrial environment for four years. (CFRP-L 71 couple; L 71 given Alocrom 1200 treatment; bolted, dry assembled; paint stripped and metal cleaned.)

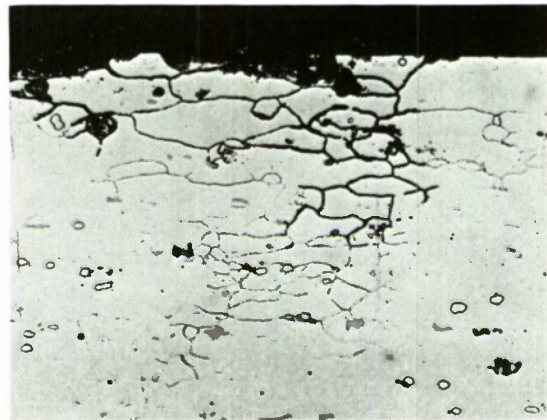


FIG. 9. Intergranular attack below surface pits in painted L 71 after exposure to marine environment for four years. (CFRP-L 71 couple; L 71 anodized; bolted, wet assembled.)

attack on the metal. In general the corrosion was more severe at the industrial site than at the marine site. The advantages of wet assembly were more apparent in the natural exposure trials. Dry bolted couples showed quite extensive corrosion under the CFRP coupons, the attack often being concentrated around the bolt holes. In the wet assembled specimens this

hidden corrosion was almost completely eliminated. After four years' exposure all of the bolted specimens showed pitting around the edges of the CFRP coupons; this was not so severe as that developed in the accelerated test and in practice would be dressed out and a local protection scheme applied.

Neither the painted metal control specimens nor the painted adhesive bonded specimens suffered any corrosion during exposure to natural environments for four years. The painted bolted specimens, however, showed the same types of attack as the equivalent unpainted specimens though the attack was less pronounced. There was virtually no corrosion of metal away from the CFRP. The corrosion found on stripping a painted dry-bolted CFRP to L71 couple after exposure on the industrial site for four years is shown in Fig. 8. An undesirable feature was that corrosion was only revealed after completely stripping the paint. Thus, the specimen shown in Fig. 8 gave no indication of corrosion before stripping. Although the attack may not appear serious the surface pitting may be accompanied by quite extensive intergranular corrosion (Fig. 9).

Corrosion of Couples between CFRP and Cadmium Plated Mild Steel

The results are summarised in Table 5. The plain specimens resisted corrosion well in the accelerated test and at the marine site; however, corrosion resistance in the industrial atmosphere was poor. Dry bolted specimens in the accelerated test showed more attack than any others, with heavy rusting all round the CFRP coupon, the rust penetrating below the CFRP. The wet assembled couples also showed heavy rusting, but the corrosion did not penetrate below the CFRP. The adhesive bonded samples showed no localised accelerated attack. The appearance of representative specimens after accelerated testing is shown in Fig. 10. The paint scheme used was effective in reducing the rate of general and localised corrosion in all cases but especially in the industrial environment.

Corrosion of Couples between CFRP and Stainless Steels

Accelerated tests showed no evidence of general corrosion or local pitting after exposures for up to nearly six months for couples with either the stainless austenitic steel (S521) or the high strength stainless steel FV 5205. In these tests the CFRP was Type I carbon fibre in Shell 828 resin matrix; the coupons

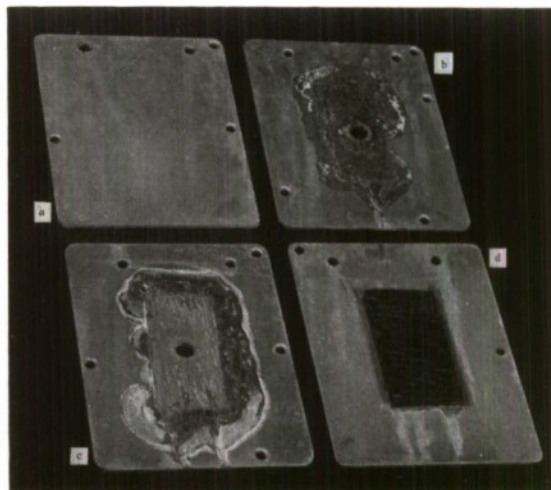


FIG. 10. Cadmium-plated mild-steel specimens after exposure to salt fog.

- (a) Uncoupled metal; exposed six weeks
- (b) Bolted couple; dry assembled; exposed two weeks; CFRP removed
- (c) Bolted couple; wet assembled; exposed two weeks; CFRP removed
- (d) Adhesive bonded couple; exposed six weeks

were cut from a 3 mm. thick unidirectional laminate containing 50 wt-% fibre. This may be taken to show that over a period of 10 to 15 years there is little danger of aggravated corrosion in CFRP-stainless steel couples.

Unpainted CFRP-S521 couples exposed on the two available sites for five years showed no corrosion. The only visible change was a dulling of the metal surfaces.

Corrosion of Couples between CFRP and Titanium Alloy

Couples between CFRP and Ti-6Al-4V sheet were exposed for six weeks to 3% NaCl fog and for six months to a 5% aqueous NaCl fog. No corrosion was observed.

Specimens exposed at the two natural sites for five years showed no signs of corrosion although the original metal surfaces had become dull.

Discussion The greater the potential difference between two materials in an electrolyte the greater will be the tendency to galvanic corrosion if they are coupled together in the electrolyte. As a rule-of-thumb it is often suggested that two materials may be considered as compatible if the potential difference between them

does not exceed 0.25V. The tendency for accelerated attack of aluminium alloys or cadmium coupled to CFRP must therefore be high (the potential difference is about 1V) while it will be much less for CFRP to stainless steel couples; CFRP and Ti-6Al-4V can be regarded as fully compatible.

Nevertheless, the severity of the galvanic corrosion, which is proportional to the current density at the anode, depends on many factors in addition to the open circuit potential difference. Probably the most important of these is the polarization of the couple. The couples with CFRP polarize very strongly, so that the corrosion currents are smaller than might have been expected. Thus, although the Cu-Zn couple has a lower open circuit potential difference (0.8V in the same electrolyte), the corrosion currents are an order of magnitude greater than for the CFRP-aluminium alloy couple. With CFRP-stainless steel couples the corrosion currents are very small (about two orders of magnitude less than those for Al alloy couples) while those for CFRP-titanium alloy couples were too small to measure reliably. Another factor of great importance is the ratio between the area of the anode and that of the cathode. All of the electrochemical measurements were made with a ratio of unity. Clearly, where large areas of CFRP (cathode) are in contact with small anodic areas it may be expected that the severity of the attack on the anodes will be greater. This factor should be considered in any design.

The simplest method of stopping the aggravated corrosion is to ensure that the CFRP is electrically insulated from the metal. This is feasible using adhesive-bonded joints. However, in the case of aircraft, limits are placed on the total electrical resistance of the structure and these limits would have to be considered at the design stage; if it became necessary to use conducting straps bridging the joints in order to reduce the resistance there could be some loss in the weight saving accruing from the use of CFRP.

Painting greatly reduces the severity of the corrosion. However, after four years' exposure at both an industrial and a marine site, painted CFRP-aluminium alloy couples with low electrical resistance show localized pitting. This attack is not severe, but would require attention. As CFRP is likely to be of greatest advantage in highly stressed areas where absolute integrity of structure is

required, dressing out corrosion damage may present problems. A disturbing aspect of the corrosion of painted specimens was that it was not readily detected by examination of the painted surfaces.

The use of wet assembly methods to reduce corrosion in aircraft structures is widely adopted in this country, though not in others. The results obtained in the present study suggest that, at least for CFRP-aluminium alloy joints, while wet assembly virtually eliminates corrosion at the CFRP-metal interface it can lead to concentration of the attack and thus to severe pitting.

The absence of any visible corrosion on both the stainless steels and titanium alloy is most encouraging. The use of laminated joints between CFRP and these metals is being extensively considered for load transmission from CFRP structures; there should be no corrosion problems in such structures.

Conclusions The present work shows that the predicted aggravated corrosion of the metal component in aluminium alloy or cadmium-plated mild-steel to CFRP couples does occur when the metal and the CFRP are in electrical contact in a conducting medium. In accelerated tests the attack, especially on 99% aluminium, is very severe, and although painting with specified aircraft finish considerably reduces the rate of attack it does not prevent it. Natural exposure for four years shows the same pattern of attack, though the severity is less. Here again painting slows the attack but does not eliminate it. At least in the early stages of corrosion, attack of the metal is not revealed by visible signs on the painted surface. Normal surface treatment of aluminium alloys by anodizing or giving a chromate conversion treatment does not afford protection.

In the case of electrically insulating adhesive-bonded joints there is no accelerated attack.

There appears to be no risk of dangerous galvanic corrosion of the metal component of CFRP to stainless steel or titanium alloy couples in saline environments.

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EXPERIMENTAL RESULTS ON DIELECTRIC-LOADED ANTENNAS WITH REDUCED DIMENSIONS

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Abstract

The general concept of reducing antenna dimensions by coating the structure with a high permittivity dielectric material is introduced and measurements are presented to show the effect on resonant monopole, Yagi and slot antennas. The bandwidth, radiation resistance, radiation patterns and temperature sensitivity are examined and the power loss in the material is recognised as the crucial parameter that constrains the usefulness of this loading technique. It is concluded that there are many immediate applications where the technique could be applied but the need for further research into ceramic materials is apparent.

While electromagnetics is one of the less fashionable research topics today there is an increasing demand for improved electromagnetic devices and in particular antennas. To some extent this is due to the availability of new materials and manufacturing techniques but the main influence is the increasingly severe constraints imposed by the system requirements. A sophisticated system is very dependent on well-optimised component parts and in many instances the antenna is one of the most critical parameters. A common and consistent requirement is for antennas of reduced dimensions but the difficulties associated with supergain are well-known and improvements in this respect have been very slight. In this article we describe a new approach⁽³⁾ to this problem whereby the antenna fields are condensed in a dielectric cladding to achieve a reduction in size.

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TABLE 1.

Dimensions, materials and summary of results for coated monopole experiment.
 T.D.=Titanium Dioxide powder B.T.=Barium Titanate powder

Case	AA	BB	CC	DD
a (cms)	0.3	0.3	0.3	0.3
h (cms)	7.6	3.85	2.15	1.65
Dielectric material	none	T.D.	B.T.	B.T.
ϵ_r	—	18	90	90
b (cms)	—	5.1	5.1	10.0
Resonant frequency (MHz)	900	900	910	900
Bandwidth (MHz)	236	145	104	144
Resistance at resonance $r_R(\Omega)$	38.8	12.5	5.5	5.4

The concept is very simple as follows. If an antenna radiates into a dielectric filled atmosphere of relative permittivity ϵ_r , the wavelength and hence the electrical dimensions need to be scaled down by a factor $(\epsilon_r)^{1/2}$ to obtain similitude with the propagation in free-space. One might expect some scaling down in dimensions and impedance levels if the dielectric region is only of finite extent but then the radiation patterns might be modified as the waves diverge from the dielectric-air boundary. Intuitively one may reason that the scaling down factor for finite dielectric coatings will be somewhere between unity and $(\epsilon_r)^{1/2}$ but other effects are apparent. In particular the waves will suffer multiple reflections within the dielectric coating and resonance effects are likely. Furthermore the reflection process means that the leakage of energy to radiation could be overshadowed by losses incurred in the dielectric material since the internal waves will traverse the material many times before dying away.

This physical picture shows that the usual supergain problems of narrow bandwidth and high loss are likely to emerge but the question remains as to what usable size reductions can be realistically obtained using modern materials and what other effects will arise. This then has been the starting point of research into this technique for reducing antenna size and in this article we describe some basic experiments on three types of antennas; these tests reveal the

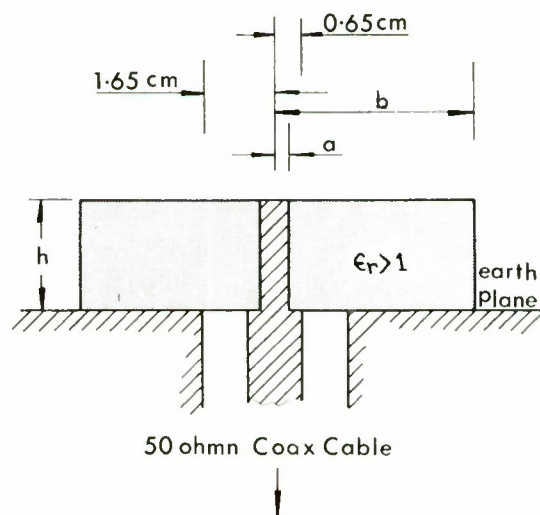


FIG. 1. Cross sectional sketch of coaxially driven cylindrical metal unipole surrounded by cylindrical slab of dielectric material of relative permittivity ϵ_r .

salient effects of the technique and indicate that it should be possible to obtain worthwhile size reductions with existing materials. Subsequently it has been found necessary to carry out detailed calculations to assess the antenna performance more precisely and some comments on progress in this respect are included together with up-to-date recommendations.

Dielectric coated wire monopole

The simplest case to experiment on is the resonant monopole fed through a ground plane by a coaxial cable; the details are given elsewhere⁽¹⁾ and are summarised as follows. A monopole was adjusted to resonant length and then coated with dielectric material; for convenience powdered material was used and it was found that the height needed to be reduced to achieve the same resonant frequency. The antenna assembly is sketched in Fig. 1 and the results for different powders are given in Table 1. The values of the relative permittivities are likely to be very inaccurate and are based on estimates for an air/powder mixture. However the results bear out the anticipated physical behaviour and suggest that the volume of material could be considerably reduced if a higher permittivity material is employed.

More recent calculations⁽²⁾ have revealed the parameters that control the resonant behaviour and it is now possible to calculate the size of the dielectric coating. It is confirmed that the coating acts as a resonator and the resonances are accounted for by both radially transverse wave motion and longitudinal wave motion. The radial type resonance seems to be most pronounced and yields a dipole-like radiation pattern; calculations show that longitudinal modes generally produce dipole patterns and this has been confirmed by experiment. A typical calculation is as follows: fused titanium dioxide has nominally $\epsilon_r=100$ and $\tan\delta=0.0003$ and for a reduction in monopole length of 80% the diameter of the coating is $0.04\lambda_0$. Calculations show that the antenna loss will be between 1 and 2 dB with a Q of about 500; at 100MHz a quarter-wavelength whip antenna will be reduced from 75 cm. to 15 cm. in height with the diameter increased to 12 cm. The bandwidth will be of the order 200kHz and the input impedance is likely to be reduced by about the same factor as the height. The analysis of the input impedance is not yet complete but the experimental results give a good guide to the impedance level that will be obtained. A variety of ways of matching into the device are under consideration and this is not considered to be a problem although some additional small loss may occur in the matching arrangement. Experiments are now taking place with distilled water as the dielectric medium since the properties of water are well documented; results so far confirm the above estimates.

The size reduction offered by the dielectric loading technique amounts to a reduction in

height at the expense of base width and this rules it out for a lot of application. We are aware of other narrow bandwidth applications however where low height is of paramount importance and for these a squat antenna is quite an attractive alternative to a long wire whip even with a loss of 1-2 dB.

It is clear that the feasibility of the loading technique depends critically on the existence of suitable dielectric material and there is much material research that could be done in this respect. For transmitter applications the behaviour of the dielectric material with high field strength must be considered and for all applications the temperature sensitivity of ϵ_r and $\tan\delta$ must be known so that the antenna performance can be calculated over the range of ambient temperatures. Ceramic filters have provided much experience in this respect; for instance without any form of temperature compensation the fused titanium dioxide coated antenna described above will experience a shift in resonant frequency of about 50 kHz per degree centigrade which is totally unacceptable for narrow bandwidth operation. Such problems have been alleviated in ceramic filters and improvements are possible.

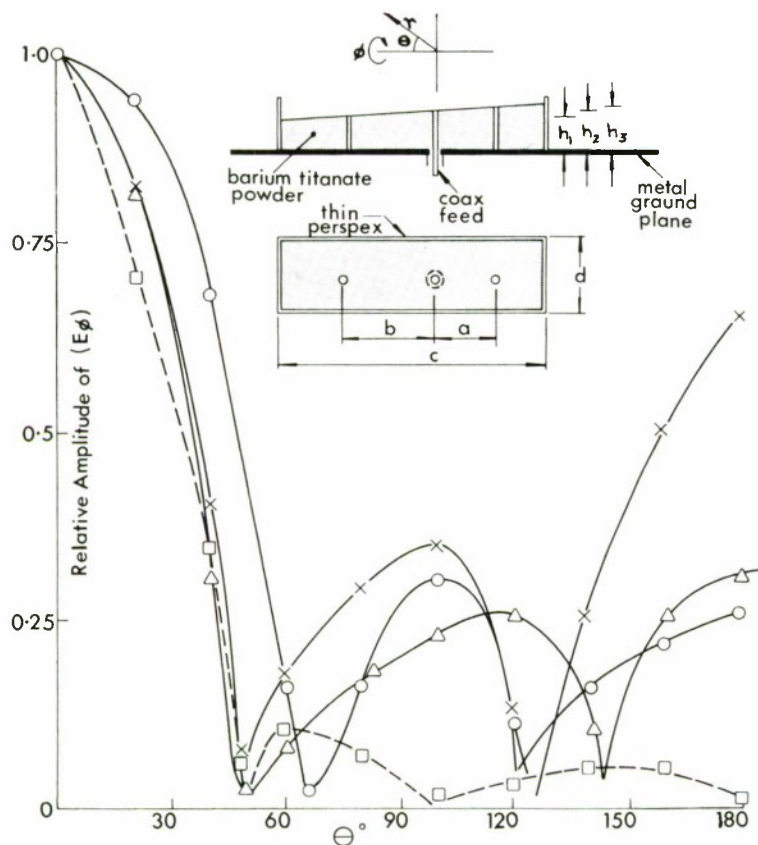
Before leaving the coated monopole it is interesting to note the similarity with the conventional ferrite rod antenna. They are in fact magnetic and electric counterparts of the same field compression principle but in our research so far we have concentrated on resonant action. The ferrite rod antenna in its conventional radio role functions at too low a frequency to invoke internal resonances and the dielectric loaded antenna could also be operated in this way; this is being considered. The consensus of opinion at present amongst material manufacturers is that modern dielectric materials offer more scope and flexibility than ferrite ones in the frequency ranges of interest; field compression by a material with both a high permittivity and permeability may offer interesting impedance properties. Other monopole configurations both with and without a central metal conductor are being considered.

We now show that the dielectric loading technique is applicable to more complex antennas and we give details of radiation patterns and impedance plots for a coated Yagi antenna. No analysis has so far been carried out for these more complex forms but it is reckoned that loss factors and temperature sensitivity can be judged by comparison with the monopole case.

TABLE 2.

Dimensions and summary of results for coated Yagi experiment; a , b , c , d , h_1 , h_2 and h_3 are defined in Fig. 2, f_R =resonant frequency, r_R =radiation resistance, Δ =% bandwidth about resonance, w =beamwidth of main lobe of radiation pattern and s is sidelobe level relative to main beam. The element diameter was 0.6 cm. in every case. Case A is the unloaded antenna.

Case	a	b	c	d	h_1	h_2	h_3	f_R	r_R	Δ	w	s
A	7.5cm	9.6cm	—	—	6.45cm	7.5cm	7.65	870MHz	24 Ω	18.8%	78°	−10dB
B	7.5	9.6	28.0	10.0	2.18	2.55	2.61	1000	11	10.5	56	−4.4
C	2.55	3.26	19.0	10.0	2.18	2.55	2.61	1000	15	15.5	54	−10
D	—	3.26	16.5	10.0	2.18	2.55	—	1000	17.5	26.5	42	−20



Dielectric coated Yagi array

A three element monopole Yagi array was arranged on a 2.1 m. \times 2.1 m. metal ground plane (about $7\lambda_0$) with provision for measuring the radiation pattern and also the input impedance by the V.S.W.R. method. The dimensions are given in Table 2 Case A and correspond to the sketch inset in Fig. 2; the element spacing was chosen for maximum gain based on recommendations by Cheng and Chen⁽⁴⁾ and the E plane radiation pattern and input impedance plots are shown in Figs. 2 and 3 respectively to illustrate the overall characteristics; the salient issues of radiation resistance r_R at the resonant frequency f_R , percentage bandwidth Δ , beamwidth w and sidelobe level s are tabulated in Table 2.

FIG. 2. Relative radiation patterns of Yagi antenna in horizontal ground plane measured at the resonant frequency which for cases B, C and D is 1000 MHz and for case A 870 MHz;

—○— case A, —×— case B,
—△— case C, ---□--- case D.

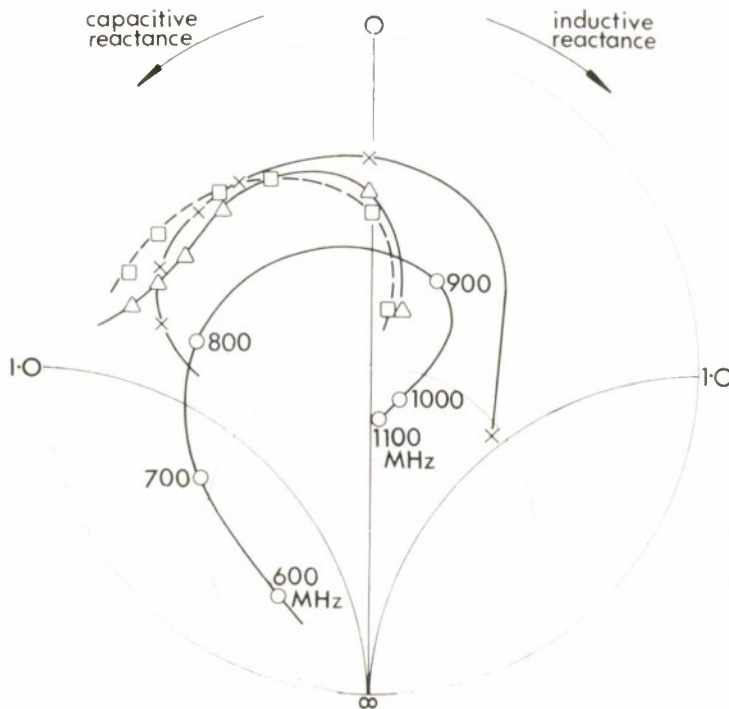


FIG. 3. Smith-chart plot of Yagi antenna input impedance normalized to 50Ω : —○— case A, —x— case B, —△— case C, ---□--- case D. Frequency range in each case is 600 - 1100 MHz in 100 MHz increments.

The following three experiments show the effect of a dielectric coating which consisted of barium titanate powder ($\epsilon_r \approx 90$) packed down into a wedge shaped region as sketched in Fig. 2. In case B the element spacings of case A were retained but the element lengths reduced to maintain resonance near to the uncoated case. The coating produced a tuning effect and lowered the radiation resistance but the radiation pattern had a large backlobe and narrower main beam suggesting that the element spacing was not optimum. In the next experiment case C the element spacing was reduced by the same factor as the height and a much improved radiation pattern resulted; a series of tests were then carried out to ascertain whether the director and/or reflector element could be removed from the dielectric wedge but it was clear that the directional properties of the antenna were very much dependent on the presence of the passive elements. Finally we show details of case D which gave a most interesting result; here the reflector element of case C was removed but the rear end of the wedge metallised; a slightly more directional pattern was obtained with lower sidelobe level, the radiation resistance was only moderately reduced and the percentage bandwidth actually increased. Our conclusions are that the metal

elements or screens continue to dominate the radiation pattern characteristics while the main effect of the dielectric materials is to reduce the dimensions and impedance levels; a saving of length of $\frac{1}{3}$ was achieved at best but the use of fused ceramic material would offer further attractive reductions in height and length.

Dielectric loaded slot antenna

Tests have been carried out on the resonant slot antenna as used on aircraft structures. The antenna consisted of an end-fed slot cut in the edge of a metal plate and the dielectric loading consisted of titanium dioxide powder ($\epsilon_r \approx 18$) held in position by a thin plastic skin. The overall trend was similar to that experienced with coated wire antennas and we summarise as follows. The experiments were performed around 1000MHz and a necessary reduction of slot length of 20% to maintain resonance was typical for a variety of slot widths; the percentage bandwidth also decreased from 18% to 10% but a surprising characteristic was that the radiation resistance increased by 50%. These tests were also repeated at 100MHz using ferrite loading and this again produced similar results with again an increase in radiation resistance. The radiation patterns in all these experiments showed some radiation effects

due to the finite metal plate but apart from this the loaded antennas showed little divergence from the dipole-like behaviour of the unloaded ones.

Discussion The dielectric loading technique has been demonstrated on a variety of antennas and the more recent⁽²⁾ results for the coated monopole show that a height reduction of 80% can be realised with existing ceramic material without excessive antenna loss but the temperature stability is a problem due to the narrow band operation. It seems likely that non-resonant operation as in the ferrite rod antennas, may be preferable in order to reduce the temperature sensitivity and this is being considered.

Greater size reductions can be obtained by using higher permittivity material but losses become more critical; calculations show that the $\epsilon_r \tan \delta$ product needs to be kept small for low loss. Tests have been carried out on fused ceramic coated monopoles with $\epsilon_r \approx 3000$ and $\tan \delta \approx 0.01$ and confirm the expectation of higher loss; evidence exists however that these losses were significantly lower than those for the uncoated monopole of the same length and this may prove to be a valuable property of the technique when viewed against the background of a complex system requirement. For

instance it is known that a considerable portion of power is lost in slot antennas when applied to smaller aircraft and with this constraint some dielectric loading in the slot may give an improved margin of operation to the overall system. Many other applications suggest themselves and the immediate requirement is for a better selection of low loss, temperature stable ceramics to be evolved together with a thorough investigation of all aspects of the technique; the latter is in progress.

Acknowledgement

One of us (J.R.J.) would like to thank P. C. Newman and H. C. Wright of the Allen Clark Research Centre, Plessey Co. Ltd., Caswell for many helpful discussions and making available sample ceramic antennas.

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DEFENCE APPLICATIONS OF THE MIRFAC LANGUAGE

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Abstract

The programming languages MIRFAC and MIRA have been developed at RARDE with the central aim of easing the task of communication with computers for non-professional programmers. Since such people constitute the bulk of Defence computer users the potential range of application of these languages is wide. An account of their distinctive features is presented, together with some applications to Defence problems and some comparison with "standard" languages.

Introduction This article presents an account of the programming languages MIRFAC and MIRA and illustrates their present or potential application in Defence scientific work. Both languages were designed by the writer, and MIRFAC, the parent language, has been in general use at RARDE since the end of 1966. The first part of the article is devoted to a discussion of MIRFAC; while MIRA, which is a special purpose language for symbolic mathematics, is treated in the second part.

Part 1: MIRFAC

Design aims of MIRFAC

All programming languages exist for the purpose of easing the problem of communication between the computer and the user. The justification for the existence of any particular language must rest upon the proposition that the use of that language makes the communication problem significantly easier for a sufficiently large group of users or a sufficiently large class of problems. From this viewpoint, MIRFAC is to be regarded as a general purpose applications language designed for use by non-professional programmers, who constitute nowadays by far the largest group of users; its principal fields of application are scientific computation, computer aided design, information handling, and — *via* MIRA — symbolic mathematics.

While it is true that all programming languages must of necessity possess certain basic features in common, it should nevertheless be noted that MIRFAC is not consciously related to any other programming language whatever. It represents an attempt to design a language *ab initio* according to the following criteria:

1. It should be easy and natural for the user to write. In this context, "natural" has been taken to mean that any equations in a problem should be capable of acceptance by the language without any transliteration from standard textbook notation being required, and that other commands are expressed in a "plain English" form which aims to be explicit rather than extremely concise.
2. It should not require the user to supply any information to the compiler which is not directly relevant to his problem. Experience shows that the non-professional programmer makes a great many mistakes by forgetting to observe the conventions of declaration which the standard languages require; and it is not until he has removed these that he can begin to discover the mistakes which he has made in the statement of his problem.
3. It should be easy to read. The importance of this requirement can hardly be overstressed. It is true that, in the last resort, a programme written in any ex-

tant programming language is difficult to apprehend as a whole because the problem must be minutely fragmented before the language is capable of expressing it. It is possible, nevertheless, to ease the position very considerably by making the individual statements easy to read, so that the programme serves to a large extent as its own documentation.

The reader will no doubt form his own opinion about the degree of success with which these aims have been met; that the aims are important is hardly to be disputed.

Implementation

It will be evident, from the examples presented in the article, that MIRFAC programmes require a specially designed terminal, since the character set and other facilities offered by those in general use are quite inadequate for the purpose. The current version of MIRFAC was developed using tape-punching Friden Flexowriters with 88 typed characters, red/black ribbon, and platen rotation both upwards and downwards. (Since it may not be apparent that a character set of this size is adequate for the purpose, we reproduce it in Fig. 1.) These machines were produced by Friden to our specification, but there is now available a Teletype terminal—the ASR 37—which has all of the necessary features. The first MIRFAC compilers were written for our computer COSMOS^(1, 2), but there is now a compiler for the ICL 1900 Series⁽³⁾. This has been run in a 1903A and in the 1904A at RAE, both under George 3, and it is now running in the RARDE 1906A under George 4.

```
lower case english a b c d e f g h i j k l m
                   n o p q r s t u v w x y z
lower case greek  α β γ δ ε θ φ ψ χ ω
                  κ λ μ ν ρ σ τ ξ η ζ
numerical        0 1 2 3 4 5 6 7 8 9
mathematical     / ÷ | . - + √ = > < > < ~
                  ( ) { } [ ] ∫ d E π ∞ -1 2 3
other            , ■ *
```

the following typewriter functions also
produce tape codes.

new line, space, red ribbon, black ribbon
half-line up, half-line down.

FIG. 1.

Principal facilities of MIRFAC

In its 1900 series implementation MIRFAC employs a 96 bit word, which permits a wide range of arithmetical options, specifically

1. Single precision arithmetic. Forty-eight bit floating point with the remaining 48 set to zero.
2. Complex arithmetic. The 96 bit word holds both the real and imaginary parts, each in 48 bit floating point form.
3. Rational arithmetic. The 96 bit word holds both the numerator and denominator of a rational fraction (for example 17/89) each in 48 bit floating point form. Rational arithmetic is exact, and numbers produced by rational operations are automatically reduced to co-prime form (any factors common to the numerator and denominator of the result are removed). This type of arithmetic is not commonly available in programming languages, but it is essential for operations in symbolic mathematics and it provides the arithmetical basis for MIRA.
4. Double precision arithmetic. Ninety-six bit floating point (available only in the 1906).
5. Fixed point bit arrays. A 96 bit word may be broken into sub-units for the purpose of packing data. Individual bytes (groups of eight bits) may be operated upon at will; and it is possible to sub-divide the 96 bit word in any desired fashion by announcing an intention to do so. This is accomplished by making initial statements of the form

Split x_n into equal parts of six

Split z into parts of 9, 3, 7, 1, 29, 8, 13, 10, 16

after which these parts may be manipulated by operations such as

put $y = x_n$ part 5
add 1 to z part m

These 96 bit arrays may be added together in a fixed point mode and may also be compared with each other. This facility is of considerable value in information handling and in symbolic mathematics.

Note particularly that the language does not require the user to make a distinction between "real" and "integer" numbers; so far as MIRFAC is concerned an integer is a "real" number whose fractional part is zero.

The ability to type in red plays an important role in the language. In the standard languages it is necessary to write $a*b$ to denote the product of a by b , since ab might itself be the name of a variable. If we wish to preserve the universally recognised convention of denoting multiplication by juxtaposition of symbols, some means must be provided for recognising a character string as a single entity. In MIRFAC this is accomplished by typing such a string in red, so that \sin typed in red is recognised as the name of a function whereas \sin typed in black in an equation would mean the product of three variables called s , i , and n . The programmer may also define functions of his own, typing their names in red, and he may give a "literal" name (such as "range" or "cash") to a variable by using the same convention; and all comment is typed in red. Where the user defines functions of his own, other such functions may appear as arguments or embedded in the body of the function statements. Recursion is thus available and has been used to good effect in the MIRA compiler.

The language offers a flexible facility for conditional statements. Its most general form is if conditions then action 1 else action 2 where each "action" may actually be a MIRFAC sentence, an equation, or an entry to one of the user's own defined functions.

All statements are numbered. In the event of an error this permits the compiler to tell the user not only what has gone wrong but precisely where it has happened. MIRFAC diagnostic facilities are explicit and informative, and are based on the proposition that a core dump is of very little use to a non-professional programmer.

A number of the facilities which have been described are illustrated by the following example, which shows a complete user-defined function. Its purpose is to print time statements according to the format

```
1ST TIME=1.032 SECS
2ND TIME=13.19 SECS
3RD TIME=.7645 SECS
```

and so on. The rule for the correct selection in all cases of the appropriate letter pair from st nd rd th is not quite straightforward.

Example

```
define function time (n)
1 n=n+1
2 put t=time now
3 put m=n mod 10
4 if m>3 then set p=1 else p=m+1
```

```
5 put q=n mod 100
6 if q>10 and q<21 then set p=1
7 print integer n only
8 print word p of th st nd rd
9 x=(t-t0)/1000000
10 print title time=x 4 secs
11 t0=t
12 time(n)=n
13 exit
```

The matter underlined in lines 10 and 12 would be typed in red. That in line 10 illustrates a further use of red typing. At run time the underlined symbols are replaced in the printer output by the current computed value of the named variable printed to the specified number of figures.

This example gives a fair impression of the "plain English" aspects of the language to which we referred at the beginning, and of the claim that, by using statements which are clear rather than extremely concise one may produce easily readable programmes which require little added comment. The equation handling capabilities of the language are demonstrated in later examples.

Applications

Design of artillery shell

One of the most striking early successes in MIRFAC applications was the development of a set of programmes for the design of artillery shell. The problem is to produce an optimum design against a set of constraints which evidently include the calibre and quite commonly include the retention of a given external profile in order to preserve ballistic equivalence. The task required the development of four computer programmes, namely

1. Computation of moments of inertia.
2. Calculation of wall stresses.
3. Determination of the centre of gravity (to ensure that the designed shell would be stable in flight).
4. Production of a computer-drawn cross-section of the shell together with a stress distribution diagram.

This set of programmes was developed over a period of about 18 months, and the final product of the last programme is normally a set of drawings giving a variety of solutions in the neighbourhood of the optimum. The reason for this is that the true optimum may call for the use of steel of such high tensile strength that the design would be uneconomic; the production of a small set of solutions enables the designer to make a final choice depending on

such additional criteria. What is remarkable about the work is that the entire set of programmes was designed and written by a professional draughtsman with no previous experience of computer programming; and the advantage claimed for MIRFAC in this instance is not that the work could not have been done using some other language, but that the intelligibility of MIRFAC encouraged a newcomer to programming to undertake an extremely ambitious task.

Computer aided design

The previous example represented the first application of MIRFAC in the field of computer aided design. (Since this phrase, like many others in the vocabulary of computing, is capable of bearing a variety of meanings, it should be pointed out that we apply it specifically to problems for which the final product is a drawing produced by a computer using a digital plotter). Subsequently the language has been used extensively for the design of fire control instruments, including gun rules, fuze indicators, and a machine-gun anti-aircraft sight. The gun rule is effectively a ballistic slide rule whose purpose is to give the user the necessary quadrant elevation corresponding to various input parameters including range and charge weight. The production of a gun rule involves a great deal of computation from range table data and the final drawing of a number of graduated scales, mostly logarithmic, and curvilinear segments derived from the range table data. This work is of considerable difficulty and has all been carried out by a

professional programmer, who developed in the process the package which generates the code for driving the digital plotters, whose facilities are built into the present MIRFAC compiler. The same programmer undertook the task of designing a machine-gun anti-aircraft sight in response to a direct request from the School of Artillery. This work was very successful, and the programmer had the terrifying (for him) experience of firing the gun with his newly designed sight himself^(4, 5, 6).

Assessment problems

Many computer applications within RARDE are concerned with problems of assessment, and this includes very elaborate computations in support of lethality studies. This is an area in which the mathematical facilities built into MIRFAC show to considerable advantage. It is a general design principle of the language that a useful facility should, if possible, be built into the language instead of requiring the user to write a procedure for it. The advantages are twofold; the writing of the programme is easier and less susceptible to error, and the resulting compiled programme is considerably more efficient in terms of running time. The example in Fig. 2 (which has been slightly simplified in order to reduce the printing problem) is taken from a programme for computing probability distributions for minelets. Examination of the defined function fn (where we again use underlining to denote typing in red) shows that what is being evaluated is a quintuple integral containing an exponential and two error functions in the innermost integrand.

The reader who is not persuaded of the advantages of being thus able to express the problem directly might translate the example into one of the "standard" languages and compare the two statements. It should also be noted that with an n -point quadrature formula the example requires $2n^5$ evaluations of the error function, so that the availability of this function as a built-in facility of the language represents a very large saving in computer time.

```

1 use low order quadrature
2 p=d[ $\int_0^{\delta'} \int_{\eta'}^{\eta''} \int_{\epsilon'}^{\epsilon''} [\rho x p \{ \delta \cdot \theta^2 + \eta_+ (v-v')^2 + \epsilon_+ (t-t')^2 \}] \underline{fn}(v, \theta, t) dt dv d\theta$ ]
3 exit

define function fn(v,  $\theta$ , t)
1 set  $\omega=1.08$ 
2  $\beta=vt \cos \theta$ 
3  $\beta'=vt+s'+5x_+$ 
4  $\gamma=s \sin \theta$ 
5  $\gamma_+=\gamma'/\cos \theta$ 
6  $f_+=c \int_{\alpha'}^{\alpha''} \underline{e}^{\alpha_+ (s-s')^2} \int_{\beta'}^{\beta''} \underline{e}^{\beta_+ (x-s)^2} [\underline{erf} \{ \gamma_+ (x\gamma+\omega) \} - \underline{erf} \{ \gamma_+ (x\gamma-\omega) \}] dx ds$ 
7 fn(v,  $\theta$ , t)=100(1- $\underline{e}^{-f_+}$ )
8 exit

```

FIG. 2.

Ballistic and allied problems

Another major field of application is that of the computation of trajectories for shell and rockets, using both point mass and six degree of freedom models. In the latter case in particular the systems of equations to be solved can become very complicated; and here too it has been found advantageous to build a facility for the numerical integration of sets of ordinary differential equations into the language itself. The method used in Gill's version of the Runge-Kutta process, and an example is shown in Fig. 3 (in the interests of brevity some of the differential equations have been omitted; in the actual programme there are 13). Note that the user is not required to specify how many differential equations there are; the end of the loop is detected (in this instance in line 68) by the occurrence of a statement which follows a differential equation but is not itself a differential equation. This causes the insertion into the compiled programme of a differential equation solving routine which generates a fourfold return to the beginning of the loop (in this case to line 52). Once again the advantages offered are ease of writing and speed of execution.

subroutine for differential equations

```

51 integrate for step in t
52  $i_1 = \sqrt{1 - (i_2^2 + i_3^2)}$ 
53  $j_3 = -(i_1 j_1 + i_2 j_2) / i_3$ 
54 enter section spinforcemoment
55  $u_1' = [f_1 - 2[\omega_2' u_3 - \omega_3' u_2] + t \cdot [\cos \delta i_1 + \cos \gamma \sin \delta j_1 + \sin \gamma \sin \delta k_1]] / m$ 
59  $x_2' = u_2$ 
63  $p_3' = g_3 + t \cdot [(\delta_3 \cos \gamma_3 + r \cdot \cos \gamma \sin \delta_3) \sin \delta - (\delta_3 \sin \gamma_3 + r \cdot \sin \gamma \sin \delta_3) \cos \delta] i_3 + b_3 j_3 + c_3 k_3$ 
64  $i_2' = -\omega_2 (i_3 j_1 - i_1 j_3) + \omega_3 j_2$ 
66  $j_1' = \omega_1 (i_2 j_3 - i_3 j_2) - \omega_3 i_1$ 
68 go to line  $\lambda$  of 85, 102, 125, 151, 178, 214
```

FIG. 3.

Part 2: MIRA

Design aims of MIRA

If a problem can be formulated in mathematical terms then it should be possible to derive one of the following types of solution:

- 1 Exact analytical
- 2 Approximate analytical
- 3 Numerical

The first of these is always to be preferred, for not only is the problem solved once and for all, but if the solution represents any kind of physical system then one can discover which are the most important parameters and how the behaviour of the system responds to

changes in them. Unfortunately there are very few practical problems to which exact analytical solutions can be found; and with the advent of the computer the emphasis has been shifted almost entirely to the derivation of numerical solutions. In many cases, however, the approximate analytical solution may be far more informative if one can carry out the sometimes formidable algebraic manipulations which its derivation entails. The idea of using a computer to perform such manipulations is consequently very attractive, and the programming language MIRA (for MIRFAC Algebra) has been designed for that purpose; it has so far been described only briefly in the literature⁽⁷⁾. Defence work offers many areas in which such a facility can be of value, since the typical problems are more often than not governed by non-linear equations. That is true, for instance, in hydro- and aerodynamic problems, in plasticity, ballistics, and vibration theory; the equations of Van der Pol and of Blasius are classic examples from the fields of non-linear oscillation and boundary-layer theory respectively. In some of these fields many years of effort have been devoted to obtaining

approximate analytical solutions by hand, always with a finite chance that the results will be wrong. (With an early version of this algebraic language the writer discovered an error in a solution of the Thomas-Fermi equation first published in 1930 and still being reproduced in the literature 40 years later; and it is hardly to be supposed that this case is unique).

In dealing with numerical problems it is always necessary for the user to concern himself to some extent with the mechanics of computer operations, since in order to obtain results he must undertake what amounts to a

type-setting exercise with a line printer. Where the input and output is made up of mathematical formulae, however, these matters can be taken out of the user's hands entirely, and it is possible to design a language in which he is not required to make any significant concession to the fact that he is using a computer. MIRA has been designed on that basis, and is believed to be the first language in the world in this field to permit communication between man and machine in text-book mathematical notation. The advantages are practical as well as aesthetic, since it is possible to produce output of such good quality that it may be copied mechanically from paper tape into a report, so eliminating the risk of transcription errors.

Implementation

To develop a tool of the kind described, two basic facilities are necessary; the abilities to work in rational arithmetic and to accept and produce mathematical expressions in standard notation. Since both are available in MIRFAC the MIRA compiler has been written in that language. The compiler operates interpretively; that is to say, it takes each statement from the user's MIRA programme in turn and decodes and executes it before proceeding to the next. The commands offered by the language are so powerful, however, that this mode of working is entirely acceptable in terms of efficiency. For instance, the first problem of any consequence to be treated by a language of this type was the solution of Cipolletti's equations (which arise in the theory of Keplerian motion of a secondary body about a primary body). The programme, written in FORMAC, was run in an IBM 7094, and took 58 seconds to produce the first 12 pairs of functions⁽⁸⁾. The same problem, written in MIRA, has been run in the 1906A and took about 17 seconds. The interested reader should consult the FORMAC paper; if it does nothing else it will convince him that the ability to work in standard text-book notation is essential in a symbolic mathematical language.

At present, output from MIRA is produced on paper tape; and that facility will always be necessary as a means of transcribing results. The acquisition of a Teletype ASR 37 terminal, however, will make it possible to work in an interactive mode; and while the writer has not had a great deal of sympathy for that idea the option has been preserved in the design of the language.

Principal facilities of MIRA

The basic aim of the language is to provide facilities for manipulating expressions of the form

$$y = \text{RHS}$$

where RHS is a sum of terms, and each term comprises a rational (or integer) coefficient multiplied by a number of variables, each of which may be raised to a positive integer power. A variable may itself be suffixed, primed (to denote differentiation), embedded in a function, or raised to a fractional power. A general idea of the possibilities may be gathered from Fig. 4. The MIRFAC facilities for typing in red have been carried over into MIRA, specifically for comment and for the names of functions. The user may also introduce complex quantities by using the "variables" *i* or *j*, typed in red (the option is provided for the benefit of electrical engineers, who use *j* where the mathematician writes *i*). To either of these entities MIRA will automatically apply the algebra $i^2 = j^2 = -1$ whenever necessary, and in output will respond with whichever of the two symbols the programmer has used. At present MIRA recognises (in the sense that it knows how to differentiate) the six circular functions, the corresponding hyperbolic functions, exponential, and natural logarithm. It is very easy for the user to introduce his own differential relations for functions, however; thus the MIRA command

$$\text{let } j_n' = nj_n/x - j_{n+1}$$

serves to define the Bessel function of the first kind. The basic commands of the language are LET, FORM, and TYPE. LET (illustrated

```

title test of recognition of zero.
let u=(2/3)-5t11cos(1/7)θ+(3/8)√t+6pq2/[x2+3y2]
let v=6t2pq/{3y2+x2}+(3/8)t1/2-5t11cos(1/7)θ+2/3
form z=u-v
type u
type v
type z
end

```

```

test of recognition of zero.
u=(2/3)-5t11cos(1/7)θ+(3/8)t1/2+6t2pq/{x2+3y2}
v=6t2pq/{x2+3y2}+(3/8)t1/2-5t11cos(1/7)θ+(2/3)
z=0

```

FIG. 4.

title legendre polynomials with test of 'if'.

```

let p0=1
let p1=x
cycle n 2 10
form pn= {2n-1}xpn-1/n - {n-1}pn-2/n
if n>4 if n≠7 if n≠9 type pn
if n=10 type pn-3
next n
end

```

legendre polynomials with test of 'if'.

```

p4=(35/8)x4-(15/4)x2+(3/8)
p5=(63/8)x5-(35/4)x3+(15/8)x
p6=(231/16)x6-(315/16)x4+(105/16)x2-(5/16)
p8=(6435/128)x8-(3003/32)x6+(3465/64)x4-(315/32)x2+(35/128)
p10=(46189/256)x10-(109395/256)x8+(45045/128)x6-(15015/128)x4
      +(3465/256)x2-(63/256)
p7=(429/16)x7-(693/16)x5+(315/16)x3-(35/16)x

```

FIG. 5.

in Fig. 4 and in later examples) simply causes the expression to be stored for further use. FORM has three modes; differential, algebraic, and complex conjugate, each of which we illustrate by a very simple example

- (1) let $x'=1$
 let $y=\sin^2 x + \cos^2 x$
 form y'
 type y'
 end

which evidently produces the output statement
 $y'=0$

- (2) let $u=1+x+x^2$
 let $v=1-x$
 form $w=uv$
 type w
 end

with the output
 $w=1-x^3$

- (3) let $y=p+iq$
 form y^*

which causes the formation and storage of the equation

$$y^*=p-iq$$

The output command is simply TYPE followed by the name of the appropriate variable. If the expression is too long to be contained within one line then the TYPE command will start new lines as necessary, never breaking up a term in the process; it also imposes a precedence on the order in which the variables in a term are typed in order to avoid any appearance of ambiguity. In particular it types functions last, because

$\frac{\tan xy}{y \tan x}$

is ambiguous whereas
 $y \frac{\tan x}{x}$
 is not.

MIRA has at present 18 other operational commands, some of which are illustrated in Fig. 5; but the language is still being rapidly developed.

Conclusions The whole article is in effect an exposition of the view that the "standard" programming languages are not suited to the needs of the average non-professional programmer who wishes

to use a computer in support of his work in some other field. To justify that view it presents accounts of a general purpose language, MIRFAC, and a related special purpose language, MIRA, both of which have been designed to meet the needs of the non-professional user with the aim of freeing him from tasks and conventions which should not concern him. It is time that the computer was put in its place.

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CORRESPONDENCE

To the Editor, Journal of the Royal Naval Scientific Service

Dear Sir,

Just a note to say how much I enjoyed Doc Rawlins's article on the physical effects of blast. I was the Diving Officer at Hornsey Island in 1949 when some of the preliminary trials were undertaken by Doc Wright using 1½ lb. TNT charges. Doc Wright was always much admired by all divers for his fearlessness, tenacity and endurance in cold water (it was midwinter). We were still using World War II equipment which was rather worn. On one occasion Doc Wright tore a cuff off his "clammy death" suit (Admiralty shallow water dress) and we repaired it using a "pusser's tickler tin". The closest dive done

by Doc Wright was 25 feet from a 1½ lb. charge and at that distance the shock is very severe.

Later in the trials Doc Wright was injured by a depth charge of 300 lb. of TNT at Spithead.

Whilst he was recovering in Haslar he calculated that if he went closer to the charge he would miss the pulse. As soon as he was declared fit he dived again at Spithead and proved his theory was correct.

Yours sincerely,

W. Y. McLanachan

Commander R.N. (Retd)

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INCHTERF, Milton of Campsie.



THE EFFECT OF WATER VELOCITY ON THE SETTLEMENT OF SWARMERS OF THE GREEN ALGA *ENTEROMORPHA*

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Exposure Trials Station

Central Dockyard Laboratory

Introduction Species of *Enteromorpha* are well known fouling organisms of ships' hulls†. These algae belong to the family Ulvaceae and are essentially marine, occurring in nature, mainly in the littoral zone or near low water level. They are, however, found in fresh water, and several of the marine species are capable of existing in a wide range of salinities, often ascending well into estuaries, especially where there is some pollution⁽¹⁾.

Several authors^(2, 3, 4) have investigated the effect of water velocity on the attachment of sedentary and boring organisms. Although there is some discrepancy in the literature as to the actual speed which will prevent settlement, it appears that none of these species will attach when the water velocity over the surface is in excess of two knots. It seems to have been generally accepted that a similar water speed would prevent the attachment of algal species. However, experience with submarines and observations in the field where settlement has occurred in situations where there is a comparatively fast flow, suggests that spores are capable of attachment even under conditions of high water velocities.

It was decided to investigate this phenomenon in the laboratory using species of *Enteromorpha* collected from Langstone Harbour. In order to obtain sufficient material for the experiments various methods were tried to increase the yield of swarmers.

Materials and Methods

Because no attempt was made to separate zoospores and zygotes formed from gamete fusion the term swarmer has been used throughout. Thalli of *Enteromorpha* were brought into the laboratory and placed in fresh seawater and the swarmers collected on release. The number obtained was extremely variable, which may have been due to the lunar rhythm⁽⁵⁾ or to some such factor as the length of exposure to air. In an attempt to obtain a more reliable yield, various treatments were applied to the thalli. Two approaches were adopted, one in which *Enteromorpha* was kept in air and treated and the other where the treatment was carried out in seawater. These are referred to for convenience as 'dry' and 'wet' treatments respectively.

The freshly collected thalli was divided into a number of samples each of approximately 100 g. which were given the following 'dry' treatments:

- (a) Untreated control
- (b) Dried under a 275 watt infra-red lamp placed at a distance of 50 cm. for periods of two, four and six hours.
- (c) Air dried for two, six and 24 hours.
- (d) Cooled to 5°C for two, six and 24 hours.
- (e) Cooled to -12°C for two, six and 24 hours.

After being treated the samples were placed in 41 beakers containing 300 ml. of a seawater Erdschreiber medium and kept at room temperature (c.18°C). Three 5 × 7.5 cm. glass slides were placed in each beaker to act as collectors. They were left in the medium for

*Sandwich Students from Hatfield Polytechnic.

†Particularly at the waterline and on submarines.

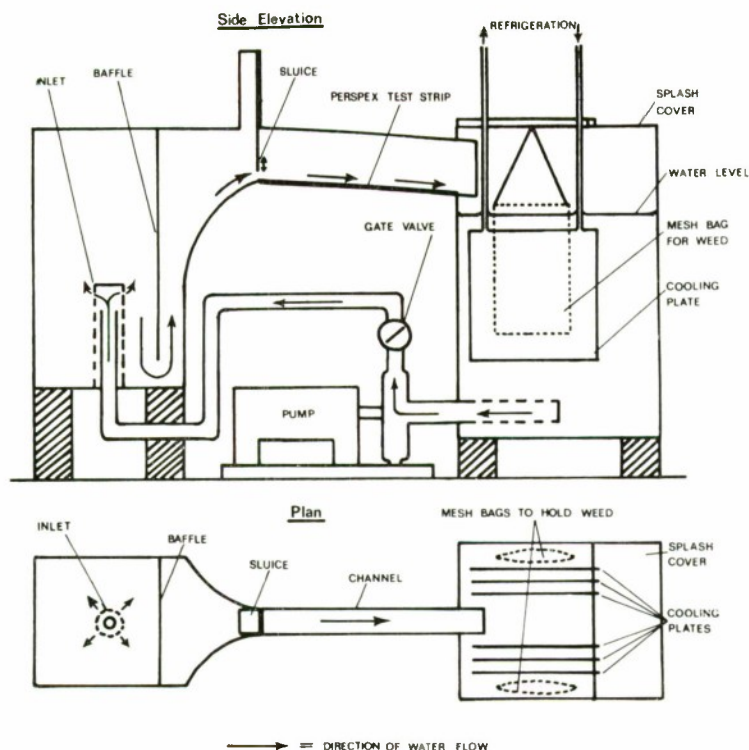


FIG. 1. Diagram of the apparatus used to study the settlement of *Enteromorpha* swarms at various velocities.

48 hours to allow swarms to settle, after which they were removed and kept in large culture trays under constant illumination for one week. The slides were then examined under the binocular microscope and the number of developing thalli recorded. An average figure for the three slides, expressed as number per sq. cm., was obtained.

In the 'wet' treatments three 100 g. samples were placed in separate beakers containing 1 litre of Erdschreiber enriched seawater and a 5×7.5 cm. glass slide. The beakers were kept in separate compartments and N_2 , O_2 and CO_2 respectively was bubbled through the water. The *Enteromorpha* was removed after two, six and 24 hours. Each slide was left for a further 48 hours before removal to the culture trays. Assessment of swarmer settlement was carried out as described above.

The apparatus used in the settlement experiments is shown in Fig. 1. It consisted of two seawater-filled GRP tanks each of approximately 250 gallons capacity. They were connected by a short 7.6 cm. diameter pipeline in which was situated a pump capable of delivering a maximum of 300 gallons per minute. On the discharge side of the pump there was a

control valve for regulating the flow of water. The tank into which the pump discharges was sealed at the top and when in use was under a positive pressure. The water flowed from one tank to the other via a $15 \times 23 \times 150$ cm. perspex channel; a sluice at the upstream end allowed further control of the seawater flow. Turbulence in the system was controlled by a baffle and a perforated inlet in the pressurised tank and by the curvature leading to the perspex channel. In the tank into which the water was discharged there were six refrigeration plates of 35,000 Btu/hour capacity thermostatically controlled. Without refrigeration a rapid rise in temperature took place; of the order of $20^\circ C$.

A strip of perspex $120 \times 15 \times 0.3$ cm. was placed at the bottom of the channel to act as a settlement surface. It was partially cut through at intervals of 7.5 cm. so that it could be easily broken without the surface being disturbed at the end of the experiment. The strip was fixed in the channel with the smooth side uppermost by means of a silicone rubber compound. This provided adequate adhesion during the experiment but also allowed the strip to be removed with ease.

The water velocity was measured by two methods. Initially an Aott propeller driven current meter was used but in later experiments velocity was determined using a Casella Pitot-static tube connected to a seawater-filled manometer. Measurements were made approximately 1.5 cm. above the perspex strip in the centre line.

At the commencement of each experiment the whole system was filled with seawater which was pumped round the system until it had reached the experimental temperature of 16°C. ($\pm 1^\circ$). The water velocity along the channel was then measured. Two plastic mesh bags, 91 \times 46 cm., half-filled with the thalli of *Enteromorpha* spp were suspended in the tank containing the cooling elements. Thus the swimmers released by the alga into the water were circulated around the system.

After three days the bags containing the alga were removed and the experiment continued for another 24 hours. When the pump was stopped the seawater was allowed to drain from the perspex channel, the strip removed and divided into its 7.5 \times 15 cm. sections. In preliminary experiments these small panels were placed directly into an Erdschreiber medium made up in seawater and cultured under constant illumination for a week at a temperature of 18°C ($\pm 2^\circ$). Each panel was then examined under a binocular microscope using 10 \times 5 cm. sweeps, at right angles to the direction of the water flow. The number of thalli per panel was recorded.

In later experiments the panels were washed with tap water or sterile seawater, after removal from the channel, to remove any unattached swimmers.

To confirm the presence of swimmers in the experimental system, three 50 ml. daily samples were taken from the channel and placed in 9 cm. diameter petri dishes. They were left for 24 hours under a uniform light intensity to allow swimmer settlement. The water was discarded, one dish was washed with sterile seawater, one with tap-water and the third untreated; they were then filled with sterile seawater and incubated and scanned under the binocular microscope as described above.

A preliminary series of four experiments were carried out in which the water velocity varied from 1.87 to 3.9 knots. This was followed by a second series of three experiments where the water speed was between 8.2 and 9.0 knots. Algal attachment was recorded as being present or absent.

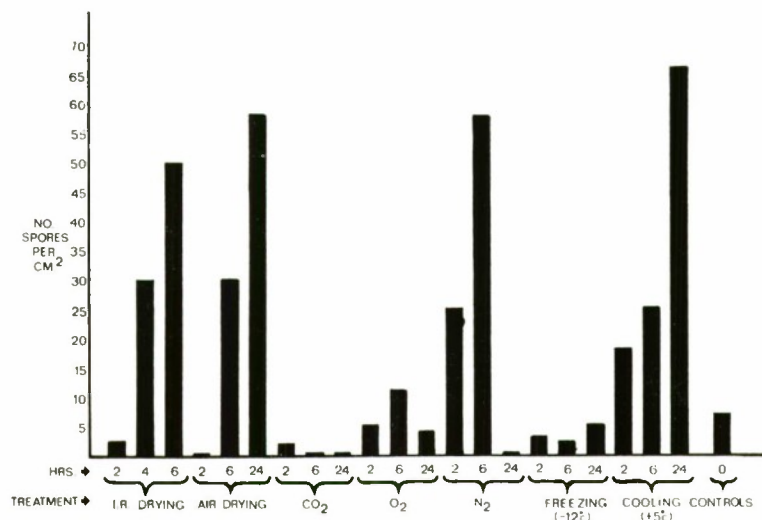
In a subsequent series the actual number of swimmers settling was recorded; the first two experiments were carried out at water velocities between 2.9 to 3.6 knots and the third between 4.4 and 4.9. A further series of experiments was undertaken at relatively high water velocities of between approximately eight and 10 knots.

Since it took 25-30 seconds for the water to drain from the channel after the pump was shut off it was possible that attachment of swimmers to the experimental panels could have occurred during that period. To investigate this possibility the system was filled with seawater which was then inoculated with swimmers and the pump turned on and left running until the channel was filled with water as in the other experiments. The pump was then switched off and the water allowed to drain from the channel. The collecting strip was treated as before, being separated into small panels, washed and cultured, after which the number of attached specimens was recorded. This experiment was repeated three times. Control dishes were set up to confirm the presence of swimmers.

Results

The results of both the 'wet' and 'dry' treatments upon spore release from thalli of *Enteromorpha* spp is summarised in Fig. 2. It can be seen that the yield of spores varied considerably from one treatment to another, and in some cases with the duration of the treatment. Bubbling CO₂ through the seawater containing the thalli had an adverse effect on swimmer production, the yield being less than that obtained in the control. Oxygen appeared to have little or no effect upon the yield. Treatment with N₂, however, presented a rather different picture. There was a considerable increase in yield with material kept for two hours in seawater through which the gas was bubbled. More than twice the number of swimmers were obtained if the treatment was continued for six hours before return to normal sterile seawater. After 24 hours the yield was below that of control.

Infra-red drying for four hours and six hours respectively, increased the yield of swimmers to almost the same level as was obtained by air drying for six and 24 hours. Thalli maintained at -12°C for 2, 6 and 24 hours showed little difference in production to the control material. Cooling to 5°C for the same periods produce a steadily increasing yield with the duration

FIG. 2. Histogram illustrating the effect of various treatments of *Enteromorpha* swarmsTABLE 1.
Qualitative results of swarmer settlement in the initial experiments.

Panel No.	Velocity in knots	Expt 1	Expt 2	Expt 3	Expt 4
1	1.9	+	+	+	+
2	2.3	+	+	+	+
3	2.7	+	+	+	+
4	3.1	+	+	+	+
5	3.3	+	+	+	+
6	3.4	+	+	+	+
7	3.5	+	+	+	+
8	3.6	+	+	+	+
9	3.8	+	+	+	+
10	3.8	+	+	+	+
11	3.8	+	+	+	+
12	3.8	+	+	+	+
13	3.9	+	+	+	+
14	3.9	+	+	+	+

+ indicates settlement.

of the treatment, and, after 24 hours, presented the highest yield recorded. Air drying of the material was adopted because of the large quantities of the alga required for each experiment and the ease with which the treatment could be carried out.

In the initial settlement experiments the water velocity in the channel varied from 1.87 to 3.9 knots. In the four experiments settlement was recorded on all the panels (Table 1). In

the second series only the first 40 cm. of the collecting strip was examined, the water speed varying from approximately 8.2 to 9.0 knots. Swarmer settlement occurred in all three experiments (see Table 2).

Subsequently the actual number of swarms settled on the collectors was recorded. In this series the first two experiments were carried out with water velocities varying from 2.9 to 3.6 knots and in the third between 4.4 and

TABLE 2.

Qualitative results of swarmer settlement from the second series of experiments.

Panel No.	Velocity in knots	Expt 1	Expt 2	Expt 3
1	8.2	+	+	+
2	8.7	+	+	+
3	9.0	+	+	+
4	9.0	+	+	+

+ indicates settlement.

4.9 knots. The numbers settling in each experiment are shown in Table 3 and the daily check on available swarmer in Table 4. Settlement occurred over the whole range of water velocities. There were indications that numbers were slightly higher at the lower as opposed to the higher end of each velocity range. In this series of experiments there also appeared to be a relationship between the number of swarmer available for settlement and the actual number settled.

TABLE 4.

The number of swarmer present in the water during the four days of the third series of experiments.

Day	Nos. settling in the Petri dishes		
	Expt 1	Expt 2	Expt 3
1	54	32	159
2	—	14	139
3	18	14	4
4	3	0	4

Four experiments were carried out in which the perspex panels were washed with either tap-water or sterile seawater before culturing. The results are given in Table 5, the water velocity in the first experiment varied from 8.9 to 9.1 and in the remainder from 10.2 to 10.7 knots. The washing procedure appeared to have no adverse effect on the results. The number of swarmer present in the system throughout the four days of each experiment is shown in Table 6. The very considerable

TABLE 3.

Number of swarmer settling on perspex sections during the third series of experiments.

Panel No.	Experiment 1		Experiment 2		Experiment 3	
	Velocity in knots	Number settled	Velocity in knots	Number settled	Velocity in knots	Number settled
1	2.9	11	2.9	1	4.4	32
2	3.0	8	3.0	7	4.4	106
3	3.1	9	3.1	4	4.5	42
4	3.2	7	3.2	2	4.5	18
5	3.3	11	3.3	5	4.5	15
6	3.3	8	3.3	3	4.5	8
7	3.3	8	3.3	150*	4.5	16
8	3.4	4	3.4	4	4.6	0
9	3.5	3	3.5	3	4.6	16
10	3.5	0	3.5	0	4.6	2
11	3.4	1	3.4	4	4.7	0
12	3.5	0	3.5	5	4.7	1
13	3.5	3	3.5	0	4.7	3
14	3.5	1	3.5	3	4.8	8
15	3.6	6	3.6	4	4.9	5

* localised clump of swarmer.

TABLE 5.
Number of swimmers settling on perspex sections during the fourth series of experiments.

Panel No.	Experiment 1		Experiment 2		Experiment 3		Experiment 4	
	Velocity in knots	Number settled	Velocity in knots	Number settled	Velocity in knots	Number settled	Velocity in knots	Number settled
1	8.9	32	10.2	5	10.2	19	10.2	10
2	8.9	66	10.2	8	10.2	6	10.2	19
3	8.9	42	10.2	5	10.2	21	10.2	6
4	9.0	18	10.2	8	10.2	2	10.2	10
5	9.0	15	10.2	5	10.2	27	10.2	7
6	9.0	8	10.2	27	10.2	0	10.2	4
7	9.0	16	10.2	0	10.2	10	10.2	7
8	9.0	0	10.3	35	10.3	5	10.3	2
9	9.0	16	10.3	5	10.3	5	10.3	7
10	9.1	2	10.3	5	10.3	2	10.3	9
11	9.1	0	10.3	2	10.3	19	10.3	10
12	9.1	2	10.3	5	10.3	1	10.3	5
13	9.1	3	10.4	4	10.4	6	10.4	15
14	9.1	8	10.7	13	10.7	7	10.7	5
15	9.1	5	10.7	0	10.7	23	10.7	0

differences in the number of swimmers present was not apparently reflected by the actual settlement as appeared to be the case in the previous series. There was also a considerable decrease in the number of swimmers in the water over the experimental period.

The results of the investigation to see

whether swimmers settled whilst the water was draining from the channel are given in Table 7 and the availability of spores in Table 8. There was a tendency for swimmers to settle in pairs on the perspex strip but this was not so marked in the petri dish cultures; the respective percentages being 36% and 5%.

TABLE 6.
Number of swimmers present in the water during the fourth series of experiments showing the comparison between different washing techniques.

Treatment	Day	Nos. settling in the petri dishes			
		Expt 1	Expt 2	Expt 3	Expt 4
Washed	1	650	1590	3000	1380
	2	223	3000	250	1000
	3	148	2000	—	444
	4	7	450	680	522
Sprayed	1	680	1020	2000	340
	2	98	3000	420	500
	3	3	2000	—	34
	4	5	740	120	852
Untreated	1	590	2000	660	5000
	2	149	3000	950	3000
	3	278	2000	—	198
	4	5	740	120	852

TABLE 7.

Number of swimmers settling on perspex sections during the period of draining the experimental channel.

Panel No.	Sprayed with tap-water Number settled			Panel No.	Washed with sterile seawater Number settled		
	Expt 1	Expt 2	Expt 3		Expt 1	Expt 2	Expt 3
1	0	0	0	2	0	1	0
3	0	0	0	4	0	0	0
5	0	0	0	6	0	0	0
7	0	0	0	8	0	0	0
9	0	1	0	10	0	1	0
11	0	0	0	12	0	0	0
13	0	0	0	14	0	0	0
15	0	0	0				

Discussion and Conclusions

In all the experiments settlement of swimmers took place on the collecting strip at water speeds up to and including approximately 10.7 knots. Although it was not possible to measure the water speed at the actual point of attachment, the conditions in the channel were reasonably representative of the water flow at least over some parts of a ship's hull. Because of the limitations of the apparatus it was not possible to increase the water velocity beyond the maximum obtained in these experiments.

It is possible that the swimmers, which are approximately 10-12 μ in diameter, enter the laminar sub layer of water adjacent to the surface and are consequently no longer subjected to the forces which may tend to remove them. If this is so then it is likely that settlement would occur at considerably higher speeds.

From the experiments it would appear that the number of swimmers settling is dependent on the number available only when that number is small.

The implication of these results is that as far as weed fouling by *Enteromorpha* is concerned settlement can occur on a ship's hull even when it is steaming at relatively high speed.*

TABLE 8.

Number of swimmers available for settlement during the draining down experiments.

Dish No.	Number settling
1	1140
2	1550
3	1500
4	1100
5	1110
6	1240
7	850
8	1130

*This has particular relevance in the provision of effective anti-fouling systems for nuclear submarine hulls.

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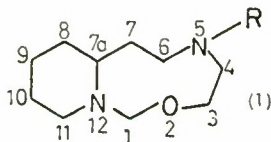
SYNTHESIS AND STEREOCHEMICAL STUDIES OF 5-ALKYL-PERHYDROPYRIDO [1, 2-c] [1, 3, 7] OXDIAZONINES

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As part of the Central Dockyard Laboratory's research programme to find an improved anti-fouling system, a series of potential organic toxins have been synthesized⁽¹⁾. The series is based on bridgehead nitrogen systems containing the moiety N-C-C-O or N-C-C-N which is present in many biologically-active systems!

The lack of data on the stereochemistry of saturated nine-membered heterocyclic systems prompted the study of the 5-alkyl-perhydropyrido[1,2-c] [1,3,7] oxdiazonine system (1). The structural relationship of the system (1)



to biologically active compounds suggested its suitability for testing as a toxin. In addition, an examination of the stereochemistry of such compounds could provide information regarding the stereochemistry of saturated nine-membered ring heterocycles.

Synthesis of 5-alkyl-perhydropyrido [1,2-c] [1,3,7] oxdiazonines

The 5-alkyl-perhydropyrido[1,2-c] [1,3,7] oxdiazonines (1) were prepared by the methods shown in Fig. 1. 2-Vinylpyridine (2) in glacial acetic acid and methanol was heated under reflux with a series of primary amines⁽²⁾ (methylamine, ethylamine hydrochlorides, and t-butylamine) to give the 2-(β -alkylaminoethyl) pyridines (3). These were then reacted with ethylene chlorohydrin to give the 2-(N- β -hydroxyethyl-N- β -alkylaminoethyl) pyridines^(3, 4).

An alternative method of synthesising (4) was the reaction of 2-vinylpyridine with a 2-alkylamino-1-ethanol in methanol and hydrochloric acid⁽⁴⁾. The methyl- and ethyl-derivatives of (4) were easily prepared by this method, but when 2-t-butylaminoethanol was reacted with 2-vinylpyridine only starting materials were isolated from the reaction mixture, probably because of the bulky nature of the attacking group.

The 2(N- β -hydroxyethyl-N- β -alkylaminoethyl)pyridines (4) were then catalytically reduced over platinum to the piperidine derivatives (5). The reduced bases were shaken with 40% aqueous formaldehyde solution at room temperature. Whereas the t-butyl derivative of (5) readily reacted with the formaldehyde to yield the corresponding 5-alkyl-perhydropyrido[1,2-c] [1,3,7] oxdiazonine (1), the methyl and ethyl derivatives were recovered unchanged from the reaction mixture. The methyl and ethyl derivatives of (5) were then reacted with 40% aqueous formaldehyde solution on a water bath, but instead of the bicyclic compound (1) being formed, the two liquids obtained were found to be 2-(N-methyl-N- β -alkylaminoethyl) piperidines (6). These compounds had thus undergone an Eschweiler-Clarke type reaction⁽⁵⁾, and evidence for this is given by the n.m.r. spectrum of (6), R=Et) as shown in Fig. 2 with the N-Me singlet at δ 2.23 p.p.m.

The 5-t-butyl-perhydropyrido [1,2-c] [1,3,7] oxdiazonine (1, R=t-butyl) when first obtained was a colourless mobile oil, but at room temperature this rapidly changed to a white waxy solid, which in evidence presented below, was shown to possess the dimeric structure (7).

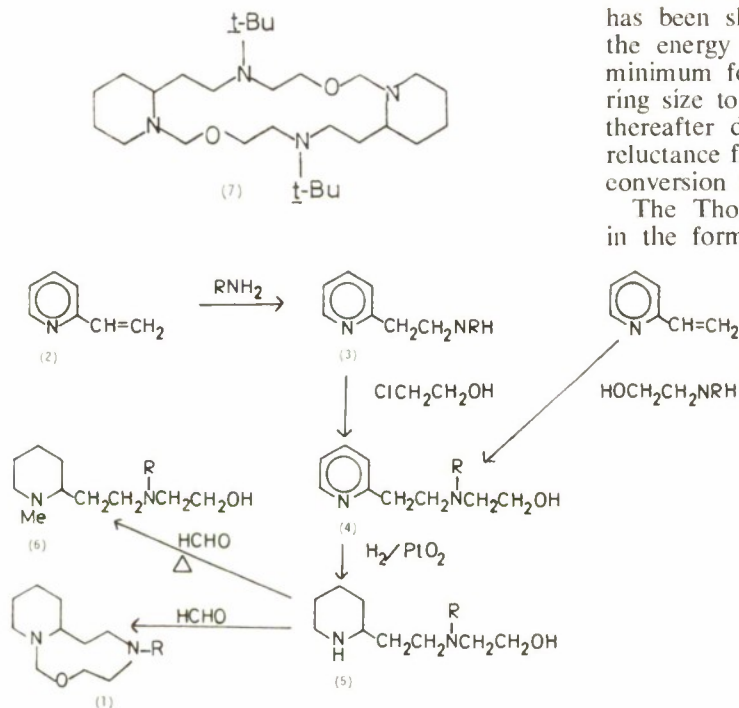


FIG. 1. Synthetic route for 5-alkyl-perhydropyrido [1, 2-C] [1, 3, 7] oxidiazonines.

Discussion of the synthetic results

Of the 2-(N-β-hydroxyethyl-N-β-alkylaminoethyl) piperidines reacted with formaldehyde only the *t*-butyl-derivative formed a bicyclic structure, whereas the methyl- and ethyl-derivatives did not react at room temperature, and when reacted at 100° formed the N-methyl compounds, rather than undergo ring closure. These observations can be explained by the high energy barrier expected in the formation of nine-membered rings, with the "Thorpe-Ingold Effect"⁽⁴⁾ (the gem-dimethyl effect), being mainly responsible for the *t*-butyl-compounds undergoing a ring closure reaction. It

has been shown that for carbocyclic systems the energy of ring closure reactions is at a minimum for cyclohexane, and increases with ring size to a maximum for cyclononane, and thereafter decreases. Thus there is a relative reluctance for an acyclic compound to undergo conversion to a nine-membered ring.

The Thorpe-Ingold effect was first noticed in the formation of some 3-membered cyclic

compounds⁽⁷⁾, when the yields were increased by starting with *gem*-dimethyl substituted reactants. The theory proposed was that the mutual repulsion of the methyl groups would increase the $\angle C$ bond angle, with a con-

sequent decrease in θ for $\angle C$. When θ was part of a small ring this resulted in ring stabilisation. Many papers have since been published, showing that this phenomenon is not restricted to methyl substituents, but that other alkyl groups show the same effect, and that the substituents need not be on the same carbon atom.

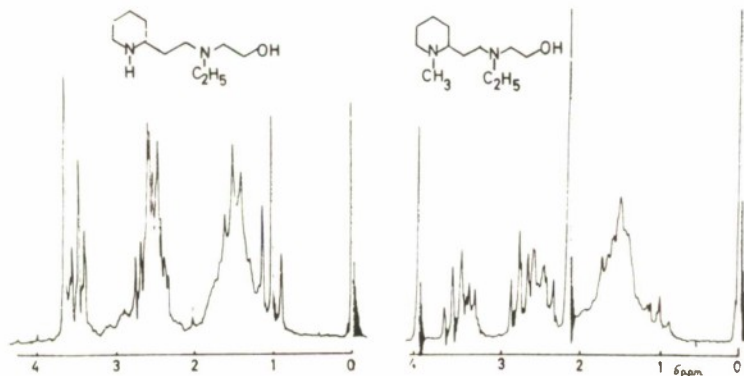
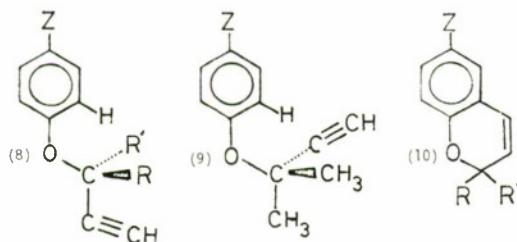


FIG. 2. 400 MHz n.m.r. spectra 2-(N-β-hydroxyethyl-N-β-ethylaminoethyl) piperidine and its N-methyl derivative.

The ring closure reactions yielding, cyclohexanes have been studied⁽⁸⁾ using the reaction n-hexane going to cyclohexane and hydrogen in the gas phase at 25° as a reference ($\Delta G = \Delta H = \Delta S = 0$). Cyclisation of substituted hexanes generally gave negative values for ΔG relative to the unsubstituted compound, and good agreement was observed for the experimental and calculated values of ΔG and ΔS , supporting the fundamental basis for the *gem*-dimethyl effect. This can also be applied to compounds containing a heteroatom. Hence alkyl substituents shift the equilibrium towards the cyclic products partly because of the enthalpy effect which is related to the change in the number of *gauche* interactions in going from the reactant to product. With alkyl substituents the transition state may contain no additional *gauche* interactions compared to the acyclic compound. The higher rotational barrier on branching leads to a smaller entropy for the branched open chain compared to the unbranched chain. The cyclic compounds lose all their internal rotational entropy, except for side chains, consequently the entropy loss on cyclisation is smaller for branched structures.

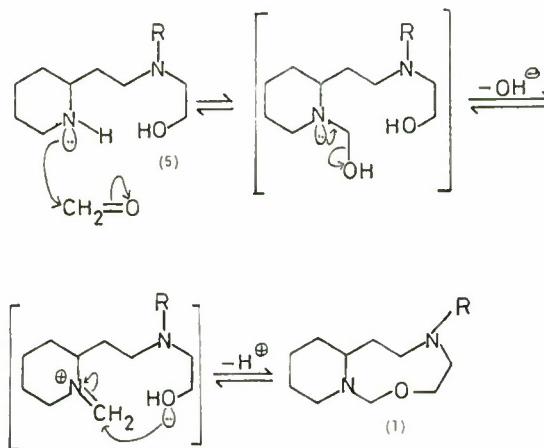
Studies have been carried out⁽⁹⁾ on the thermal cyclisations of a series of 4-substituted propargyl ethers, and the *gem*-dimethyl effect observed was thought to be a conformational effect. In compound (8), $R = H$, $R' = H$, the



lowest energy rotamer has R' closest to the ortho-H, and in (9) the lowest energy rotamer has the ethynyl group near the ortho-H, since the *gem*-dimethyl group tends to keep away from the benzene ring. This facilitates the production of (10). Further examples can be found in the synthesis of medium and large sized ring compounds⁽¹⁰⁾, where the *gem*-dimethyl groups have prompted cyclisation.

With regard to the 5-alkyl-perhydropyrido [1,2-c] [1,3,7] oxidiazonines, Dreiding models show that the number of *gauche* interactions for (5; $R = \text{Me}$ or Et) is low, and consequently the energy change (ΔE) in going from (5) to (1)

will probably be very high resulting in a lack of reaction with formaldehyde at room temperature. However, in (5; $R = t\text{-Bu}$) the intro-



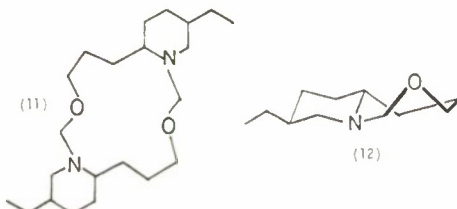
duction of the bulkier alkyl substituent leads to an increase in the number of *gauche* interactions, and the subsequent decrease in ΔE in going from the open chain structure to (1) is more favourable for ring closure. In addition, for steric reasons the bulky *t*-butyl substituent in (5) would tend to be as far from the piperidine ring as possible, resulting in a placement of the oxygen atom in a position suitable for ring closure.

Structured studies on 5-*t*-butyl-perhydropyrido [1,2-c] [1,3,7] oxidiazonine

The 60 MHz n.m.r. spectrum of the crystalline form of this compound (7) in deuterated chloroform was run at 35°. The spectrum obtained 30 sec. after the solution had been prepared showed a single AB quartet at δ 4.45 and 4.03 p.p.m., with a J_{gem} of -10 Hz which was assigned to the $N\text{-CH}_2\text{-O}$ protons (Fig. 3). The spectrum obtained after 5 min. showed a second AB quartet at δ 5.08 and 4.48 p.p.m. with $J_{\text{gem}} = -9$ Hz, and splitting of the original AB quarter was observed (Fig. 4). The n.m.r. spectrum of the liquid form of 5-*t*-butylperhydropyrido [1,2-c] [1,3,7] oxidiazonine was identical with that shown in Fig. 4. The variation of the 60 MHz n.m.r. with time is shown in Fig. 5, where the region containing the AB quartets, i.e. δ 4.5-5.2 p.p.m. was scanned.

Whilst this work was being carried out, a similar effect was observed for a series of perhydropyrido[1,2-c][1,3] oxazepines, and was shown to be a reversible dimerisation process.

X-ray crystallographic studies⁽¹¹⁾ on the crystalline product obtained from the reaction between 3-(5-ethyl-2-piperidyl) propan-1-ol showed it to possess the dimeric structure (11), which in solution was completely converted to the *trans*-ring fused monomer structure (12).



The dimer (11) and the crystalline (7) were examined by mass spectra*, obtained at 55e V and 18e V at 100°, with (11) recorded to over 366 amu, and (7) to over 500 amu. The samples were also scanned manually at a higher sensitivity, but in both cases the highest mass group recorded corresponded to that of the monomer, with no dimer ion, or any fragmentation of it detected. Thus, this method, not unexpectedly, cannot be used to detect the dimeric structures.

As mass spectroscopy is unable to detect the presence of the dimer (12), molecular weight determinations were obtained† for (7) using a Mechrolab V.P.O. at 37° with CCl₄ as the solvent. The molecular weight of benzil (10) was used for the calibration, and the results

TABLE a
Results of the molecular weight studies on
(1: R=t-Bu)

Time (min)	ΔR	MW
6	20.80	302
15	21.64	291
25	20.40	308
35	22.90	274
45	22.86	275
55	21.78	289
65	22.68	277
300	21.20	296

*the mass spectra were obtained from the Admiralty Materials Laboratory.

†The M.W. determinations were obtained from the National Physical Laboratory.

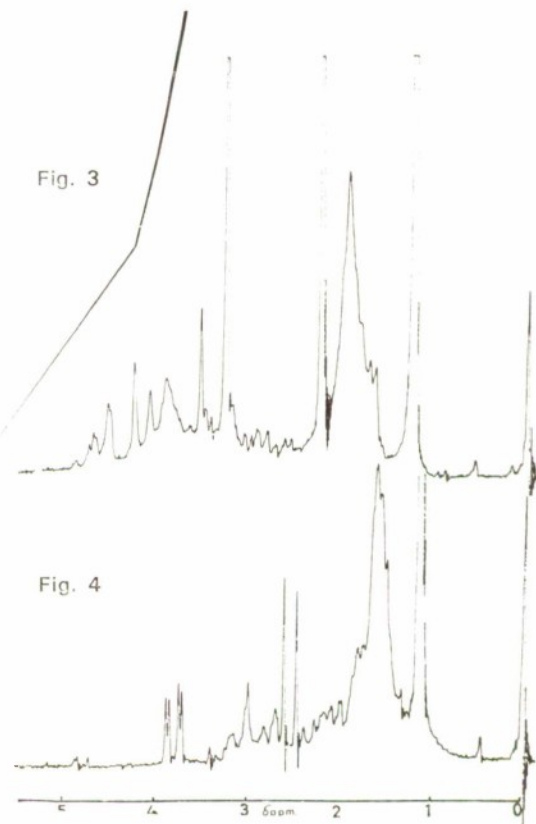
were obtained using the equation $(\Delta R/C)C \rightarrow 0 = K/MW$, where C is the concentration in g/litre (12.75 g/l), and K is the constant for the instrument (493) and ΔR the variation in vapour pressure.

The first reading obtainable was after 6 min, and the 60 MHz n.m.r. spectrum Fig. 3 indicates the system has reached an equilibrium in this time. The mean value of the molecular weight obtained was 289, i.e. between the molecular weights of the monomer and dimer of 240 and 480 respectively. In this respect the system appears to differ from that of (11) where the dimer is completely converted to monomer in solution.

The 220 MHz n.m.r. spectrum of (7) in CDCl₃, at 18°, obtained 3 min. after making up the solution (Fig. 6), showed an AB quartet δ 4.10 and 4.40 p.p.m. ($J_{gem} - 9.2$ Hz), with a second AB quartet of much lower intensity at δ 4.48 and 5.10 p.p.m. ($J_{gem} - 9.5$ Hz). The spectrum also showed a multiplet at δ 2.40 to 2.95 p.p.m. assigned to protons adjacent to the

Fig. 3

Fig. 4



FIGS. 3 and 4. The 60 MHz n.m.r. spectrum of (7) in CDCl₃ obtained 30 sec. (Fig. 3) and 5 min. (Fig. 4) after preparation of the solution.

nitrogen atoms. The spectrum after 6 min. was almost identical to that obtained previously (Fig. 6), except for an increase in the area of the AB quartet at δ 4.48 and 5.10. When the spectrum was re-run after 45 min. (Fig. 7) a third AB quartet was observed at δ 4.08 and 4.43 p.p.m. ($J_{\text{gem}} = -9.2$ Hz) and the multiplets centred at δ 3.58, 3.09 and 2.20 p.p.m. had increased in intensity. The 220 MHz n.m.r. spectrum of (7) obtained at -45° in $\text{CDCl}_3/\text{CFCl}_3$ showed a single low field AB quartet, and after storage for one week at this temperature the spectrum was unchanged. The temperature of the solution was then allowed to rise, and at -23° , a second AB quartet (δ 4.08 and 4.43 p.p.m.) appeared with a third AB quartet at δ 4.48 and 5.10 p.p.m. appearing at -2° . On warming to 19° the spectrum obtained was the same as in (Fig. 7). The 220 MHz n.m.r. spectrum obtained in deuterated pyridine at $+97^\circ$, showed a single AB quartet (Fig. 8) at δ 4.45 and 5.00 p.p.m. ($J_{\text{gem}} = -9.0$ Hz) with no evidence of other low field AB quartets.

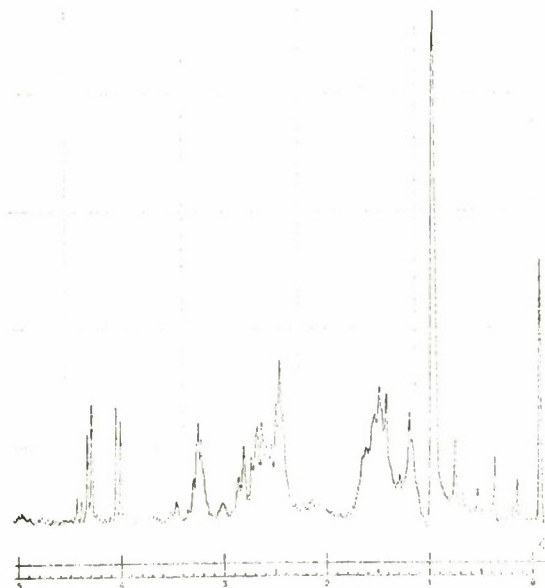


FIG. 6. The 220 MHz n.m.r. spectrum of the crystalline (7) in CDCl_3 at 18° obtained 3 min. after making up the solution.

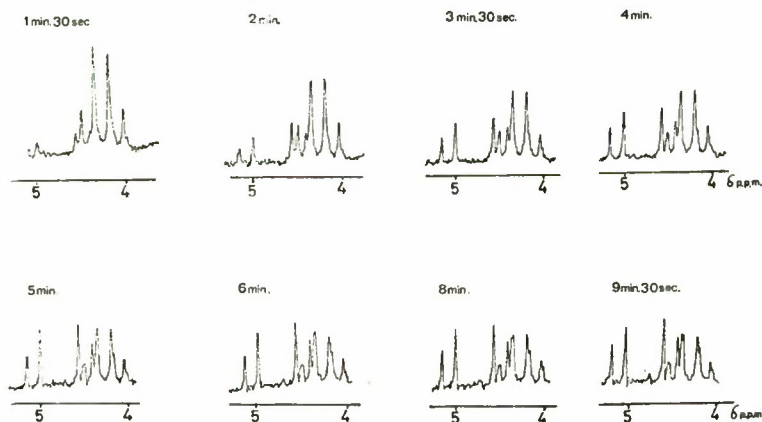


FIG. 5. The variation with time of the 60 MHz n.m.r. spectra of (7) in CDCl_3 , showing the increase in intensity of the AB quartet at δ 5.08 and 4.48 p.p.m., and the splitting of the AB quartet at δ 4.45 and 4.03 p.p.m.

The three AB quartets between δ 3.9 and 5.1 p.p.m. in these spectra indicate the presence of three species when a solution of (7) is allowed to reach equilibrium at room temperature. The chemical shifts of two of the quartets at δ 4.10 and 4.40 p.p.m. and at δ 4.08 and 4.43 p.p.m. are typical of $\text{N-CH}_2\text{-O}$ protons [cf δ 4.52 and 3.83 p.p.m. in (11) and δ 4.31 and 4.23 p.p.m. for the *trans*-fused monomer (12)] whereas that at δ 4.48 and 5.10 p.p.m. appear at too low a field for such a system. The spectrum at -45° corresponded to only

one compound, and it is not unreasonable therefore to assume that this is the spectrum of the dimeric compound (7) with the AB quartet at δ 4.10 and 4.40 p.p.m. arising from the $\text{N-CH}_2\text{-O}$ protons in the compound. Accordingly the δ 4.08 and 4.43 p.p.m. quartet may be assigned to the $\text{N-CH}_2\text{-O}$ protons in the monomeric structure (15). The chemical shifts for the AB quartet at δ 4.48 and 5.10 p.p.m. are not typical of $\text{N-CH}_2\text{-O}$ protons, but the broadening of the low field signal of this quartet in the 220 MHz n.m.r. spectrum compared to

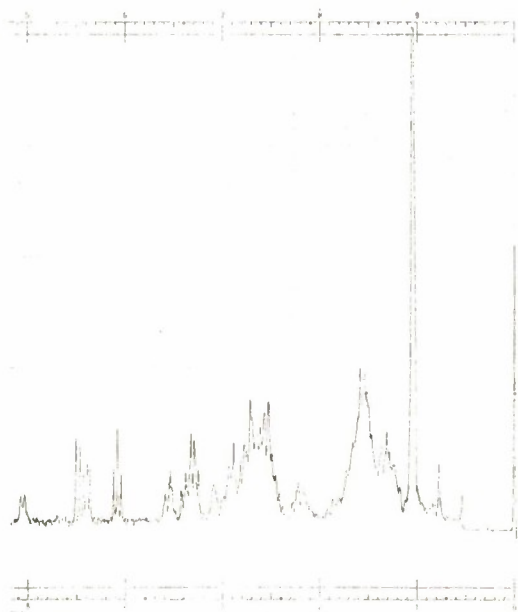


FIG. 7. The 220 MHz n.m.r. spectrum of the crystalline (7) in CDCl_3 at 18° obtained 45 min. after preparation of the solution.

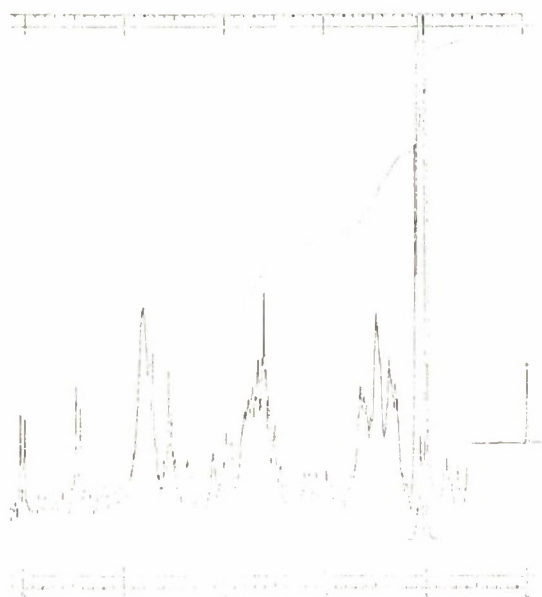
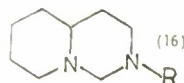


FIG. 8. The 220 MHz n.m.r. spectrum of the crystalline (7) obtained at 97° in deuterated pyridine.

that observed in the 60 MHz n.m.r. is often shown by the low field half of AB quartets arising from $\text{N-CH}_2\text{-N}$ protons. However, such protons normally absorb at higher field [cf. δ

3.53 and 2.38 in 2-methylperhydropyrido [1,2-c] pyrimidine (16; R=Me)]⁽²⁾ and it is proposed that the signals (δ 4.48 and 5.10 p.p.m.) in Fig. 7 arise from $\text{N-CH}_2\text{-N}^+$ protons, with the low field absorption of these being due to the strongly electron withdrawing quaternary nitrogen. No information, however, was available on the chemical shifts of $\text{N-CH}_2\text{-N}^+$ protons, and consequently the 2-t-butylperhydropyrido [1,2-c] pyrimidine (16; R=t-Bu) was synthesized. The 60 MHz n.m.r. spectrum of



(16; R=t-Bu) was obtained in CDCl_3 (Fig. 10) and showed an AB quartet for the $\text{N-CH}_2\text{-N}$ protons at δ 2.50 and 3.77 p.p.m. ($J_{\text{gem}} = 8.5$ Hz). When an equimolar quantity of methyl iodide was added to this solution a low field AB quartet was observed (Fig. 11) at δ 4.13 and 4.65 p.p.m. ($J_{\text{gem}} = 10.3$ Hz) which was assigned to the $\text{N-CH}_2\text{-N}^+$ protons in the methiodide of (16; R=t-Bu). The sample was not purified, but the spectrum shows the down field shift due to the positively charged nitrogen atom, and the broadening of the signal for the $\text{N-CH}_2\text{-N}^+$ equatorial proton. The spectrum of (16; R=t-Bu) was obtained in deuterated pyridine and found to be similar to (Fig. 10) with an AB quartet at δ 2.58 and 3.88 p.p.m. When an equimolar quantity of ethylene bromohydrin was added to the pyridine solution, and the spectrum re-

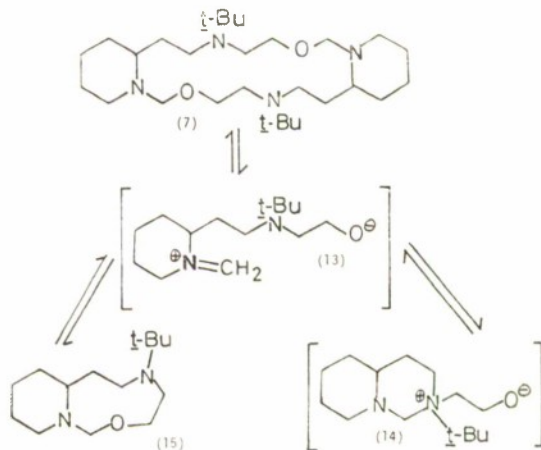
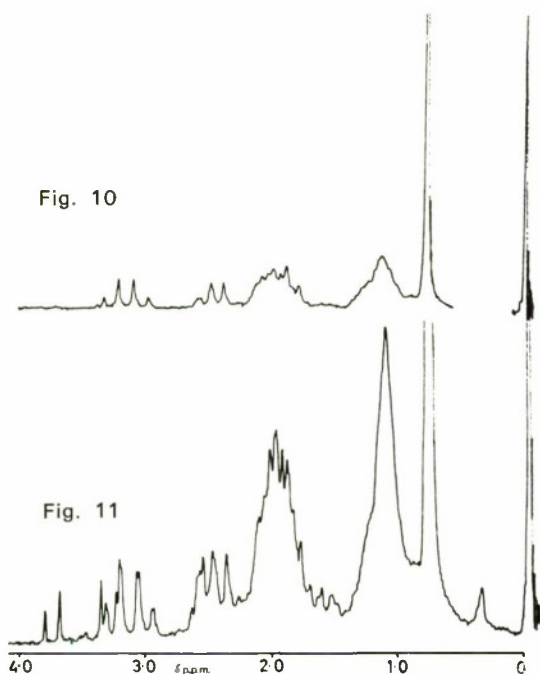


FIG. 9. Proposed equilibrium obtained when the dimer (7) is dissolved in CDCl_3 at room temperature.



FIGS. 10 and 11. The 60 MHz n.m.r. spectra of 2-t-butylperhydropyrido [1, 2-c] pyrimidine, Fig. 10, and its methyl iodine derivative, Fig. 11, in CDCl_3 .

run, it was possible to observe an AB quartet at δ 4.34 and 5.25 p.p.m. ($J_{\text{gem}} -9.8$ Hz) similar to that observed in the spectrum of 5-t-butyl-perhydropyrido [1,2-c] [1,3,7] oxadiazonine (Fig. 9). Similar results were obtained for (16; R=Me and Rt) and the results are summarised in Table b for these compounds and the methiodides.

These results demonstrate that the AB quartet at δ 4.48 and 5.10 p.p.m. in the spectrum of (7) arises from the $\text{N-CH}_2\text{-N}^+$ moiety. A consideration of the possible mechanism for conversion of dimer (7) to monomer (15) suggests the transient occurrence of the ring opened species (13), which is similar to that proposed for the (11) to (12) conversion⁽¹¹⁾. Rather than close to (15), ring closure to the perhydropyrido[1,2-c] pyrimidinium ion (14) is possible. The considerable proportion of (14) present in the equilibrium mixture is probably due to the reluctance of the nine-membered rings to form, and the stabilisation of the open chained intermediate (13) by the formation of the six-membered ring (14), with which it is in equilibrium.

Approximate concentrations of the monomer (15), dimer (7) and perhydropyrido [1,2-c] pyrimidinium ion (14) in the equilibrium mixture at 19° in CDCl_3 were estimated from the

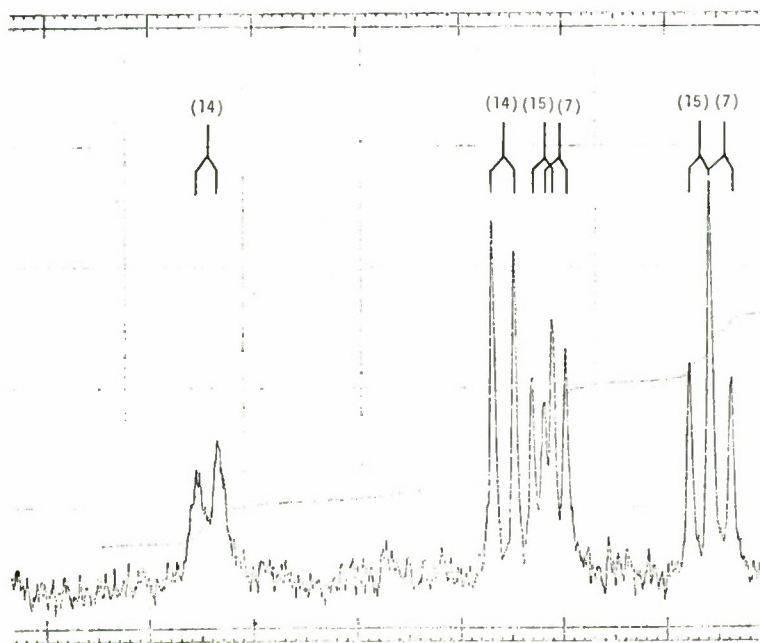


FIG. 12. Expanded 220 MHz n.m.r. spectrum of the equilibrium mixture obtained when the dimer (7) was dissolved in CDCl_3 at 19° with the subsequent formation of the monomer (15) and the perhydropyrido [1, 2-c] pyrimidinium ion (14).

Table b

The chemical shifts and coupling constants for the C(2) methylene protons of 2-alkylperhydropyrido [1,2-c] pyrimidines, and their methiodide derivations in CDCl₃.

Compound (16)	Chemical shifts (δ ppm)				Coupling constants (Hz)	
	$N-CH_2-N$		$N-CH_2-N^+$		$N-CH_2-N$	$N-CH_2-N^+$
	H_{ax}	H_{eq}	H_{ax}	H_{eq}	J_{ax2eq}	J_{ax2eq}
R = Me	2.38	3.53	3.97	4.48	-8.4	-10.0
R = Et	2.40	3.63	4.15	4.47	-8.4	-10.2
R = t-Bu	2.54	3.81	4.13	4.63	-8.5	-10.3

expanded 220 MHz n.m.r. spectrum of the AB quartets (Fig. 12). The area under each peak was measured with a planimeter when 45% of (14) was found to be present in equilibrium with 27% of (7) and 28% of (15).

It would seem, from the spectrum of (7) run in deuterated pyridine (Fig. 8) that the most stable species in solution at 97° is the ion (14), but attempts to obtain spectra at gradually increasing temperature in deuterated pyridine were unsuccessful, as (7) is only soluble in hot pyridine. The 60 MHz n.m.r. spectrum of (7) in CDCl₃ solution was obtained at 5° intervals between 25° and 55°, when an increase in the intensity of the AB quartet for the $N-CH_2-N^+$ (δ 5.08 and 4.48 p.p.m.) with respect to the AB quartets for the $N-CH_2-O$ protons arising from (7) and (15) was observed. From this evidence, and the low field absorption for the AB quartet in deuterated pyridine (δ 5.00 and 4.45 p.p.m.) in the 220 MHz n.m.r. spectrum (Fig. 8) it seems that only the perhydropyrido [1,2-c] pyrimidinium ion (14) is present in solution at 97°.

The complexity of the n.m.r. spectra, and the seeming breakdown of the Bohlmann i.r. correlation⁽¹²⁾ in bridgehead nitrogen systems of the type (10) does not allow conclusions to be drawn about the details of the stereochemistry of (7 and 16).

Preliminary raft and laboratory antifouling screening tests on the compounds synthesized

in this study indicate that only the dimeric solid 10,22-di-t-butylperhydropyrido [1, 2-c: 1,2-] 1, 10, 3, 7, 12, 16-dioxetetracyclodecine showed potential as an antifouling agent. This compound also has the desirable characteristic of having a low solubility in sea water.

Acknowledgements

I would like to thank Mr. D. R. Houghton, Officer in charge ETS and Dr. T. A. Crabb of the Portsmouth Polytechnic for their invaluable help and encouragement in this work.

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HUMAN CLOSED ENVIRONMENT STUDY COMPLETED AT INSTITUTE OF NAVAL MEDICINE



Admiral Sir Andrew Lewis visits the volunteers.

On July 24th, nine Naval ratings were finally released from the human exposure chamber in the Environmental Medicine Unit (EMU) at INM after 81 days of comprehensive medical and psychological testing within the chamber. During this time they were totally isolated from the outside world for a continuous period of 67 days. For the remaining seven days at each end of the experiment they were permitted to leave the chamber for approximately two hours per day, so that baseline measurements with access to fresh air could be determined. After a three-week control period during which the chamber air was of normal atmospheric composition, the subjects were exposed to an additional 0.5% carbon dioxide for five weeks, and then conditions were reverted to control levels for a further 11 days while recovery from the effects of the carbon dioxide was assessed. The EMU and its exposure chamber were described in an earlier *Journal*⁽¹⁾ as were the reasons why the experiment was performed⁽²⁾.

The experimental results, consisting of large amounts of physiological, biochemical, mental and physical performance, and electroencephalographic data, will take many months to analyse

and assess, but it is hoped that definitive conclusions concerning the safe level of carbon dioxide for continuous crew exposure in nuclear submarines will be reached by the end of 1974. The study has raised considerable interest by virtue of its wide-ranging nature in many non-Service scientific and medical centres, and also in the United States Navy which provided medical and technical assistance to EMU staff during the experimental period.

Among Service visitors to the EMU during the study were General Sir Richard Ward, Chief of Personnel and Logistics, Ministry of Defence, who formally released the subjects from their period of total isolation on July 18th; Admiral Sir Andrew Lewis, Commander in Chief, Naval Home Command; Admiral Sir Terence Lewin, Commander in Chief, Fleet; Surgeon Vice-Admiral James Watt, Medical Director General (Naval); and the Commanding Officers of the subjects' ships and establishments.

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INDIVIDUAL MERIT PROMOTION TO SPSO



Mr. A. G. Patterson

Admiralty Compass Observatory

After gaining an M.A., Cambridge, in Physics, Graham Patterson started his career of involvement in scientific instruments by joining George Kent Ltd. in 1937. He served in the Royal Navy for the duration of the war becoming an electrical officer and later torpedo officer in H.M.S. *Kenya*. He returned to George Kent Ltd. for a short time after the war but in 1946 entered Government Service at AEL, West Drayton. In 1952 he transferred to ACO, Slough, joining the team developing the Admiralty Gyro compass, AP5005, the first of which he installed in H.M.S. *Cumberland*.

The late fifties saw the birth of the Ships Inertial Navigation System. It was clear that for SINS to become a viable navigational system, the performance of the already complex gyros must be greatly improved. With customary foresight, the late Head of ACO, Mr. H. J. Elwertowski, launched into the unknown depths of self-acting gas bearings and gave Patterson the task of turning a concept into reality. Working virtually single-handed he laid some of the foundations of this relatively new science and very soon became an internationally recognised authority on gas bearing gyros—with the result that ball bearing gyros faded from the scene and the gas bearing era began.

Graham Patterson has travelled many thousands of miles to participate in conferences, symposia and exhibitions and to visit other gas bearing experts, chiefly in the U.S.A.



Dr. I. M. Yuille

Admiralty Research Laboratory

Dr. Yuille, head of the Computer Aided Ship Design section in Mathematics Group ARL, has been awarded an Individual Merit Promotion to SPSO.

Dr. Yuille has had a long and distinguished career in naval architecture. After serving an apprenticeship with Vickers Armstrong for most of the war years, he studied Engineering at the University of Glasgow, obtaining his B.Sc. degree. He then returned to the Design Office at Vickers for 2½ years before returning to Glasgow to take up a Post Graduate Research Scholarship in Naval Architecture. The subject of the research was the strength of ship structures.

In 1952 he joined NCRE, first as Deputy, then as Head of the Structures Testing Group. In 1960 he transferred to the Ship Department, Bath, and in 1967 transferred to ARL to lead the newly formed Computer Aided Ship Design section.

In the early part of his career he produced a number of papers on naval architecture. He was quick to see the enormous potential of digital computers as an aid to ship design, and he has shown considerable dedication in pursuit of this theme in which he has acquired an international reputation.

ADMIRALTY OIL LABORATORY



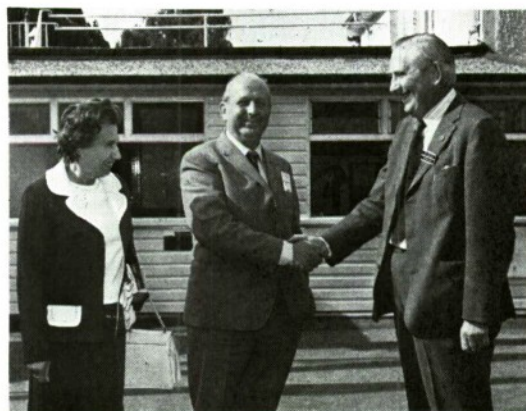
Mr. B. W. Lythall, C.S.R.N. with Dr. R. Onions of A.O.L.

During the week of 16th - 21st September the Admiralty Oil Laboratory at Cobham held a series of Open Days to celebrate its birthday 21 years after being set up at Brentford as a result of the recommendation of the Admiralty Oil Quality Committee under Lord Geddes in May 1951.

Since those early days there have been many changes in all aspects of the Laboratory but its main task is still to provide the Director General Ships with the necessary knowledge to solve naval fuel and lubricant problems.

The Scientific work of the Laboratory is carried out by three Sections: Mechanical Evaluation of Lubricants, Fleet Support and Applied Physical Chemistry. During the Open Days a main exhibition displayed the principal areas of work in each Section after which the visitors were able to proceed to the sections for further detailed displays and discussions with the staff.

21st ANNIVERSARY



Mr. Bygraves, Deputy Mayor of Elmbridge and Mrs. Bygraves being greeted by Dr. D. Wyllie.

In the Mechanical Evaluation of Lubricants Section, visitors were shown rigs which AOL had designed and built for investigating the effect of lubricants on the fatigue life of rolling contact bearings, and Disc and Gear Machines used for investigating the mechanism of scuffing. The Oil Evaluation Engine Laboratory showed the range of test engines available for developing suitable diesel engine lubricants, including the supercharged Petter AV-B engine which AOL have helped to promote as an international oil test engine. Advanced engine performance and exhaust gas analysis equipment was also on display, together with the first stage of a programme to automate the acquisition of data from engine tests in a form suitable for subsequent processing on the Varian 620L - 105 computer recently installed here, demonstrating the close liaison which exists between the academic world and AOL.

Reading University had been invited to show their technique for measuring the oil film thickness between piston rings and cylinder liners using test engine facilities provided by AOL.



General view of Main Display Area.

The Fleet Support laboratories demonstrated the wide range of chemical tests which are available for rapid analysis of samples supplied by the Fleet. These tests range from simple checks on viscosity to the more complex analysis of oils to detect traces of metals using atomic absorption spectroscopy and hence, by monitoring the variation in concentration of these metals over a period, to predict impending machinery failure. AOL provided considerable assistance at the time of the *Torrey Canyon* incident and the results of research into the structure of emulsions and fluid mechanics of oil slicks, instituted at the University of Nottingham at that time, were also on display. This section also has the responsibility for ensuring that suitable fuels and lubricants are available for all R.N. applications, and for co-ordinating the development of the necessary specifications.

The Applied Physical Chemistry Section undertakes the more complex or longer term research and investigations. An explosion tube, built at AOL to investigate the flammability of oil/air mists of varying concentrations, provided one of the more spectacular displays.

This work has been undertaken to improve the understanding of the conditions under which main propulsion gearboxes can present an explosion hazard. Another important research project is the evaluation of hydraulic fluids which are less flammable than the mineral oil based fluids currently in service. Tests were demonstrated which compared the anti-wear properties of different fluids, their compatibility with sea water, and their flammability under various conditions relevant to hydraulic systems. AOL has also been involved with the problems of running marinized gas turbines using fuel from water ballasted tanks and a rig to evaluate the efficiency of coalescer/filters in removing sea water from fuel was shown.



Visitors discussing the Petter AV1 engine.

Visitors from the Ministry of Defence, Industry, the Universities and Technical Colleges came in large numbers to the Laboratory during the Open Days. The staff and six instructors from H.M.S. *Sultan* who were seconded for duty were inundated with questions.

The standard achieved in the presentation of the many exhibits was, as one has come to expect from MIP(N), extremely high, and this, together with the enthusiasm with which all concerned had obviously approached the organisation of these first Open Days, ensured their complete success.



NOTES AND NEWS

Admiralty Underwater Weapons Establishment



Sonar Department Exhibition

The Eighth International Congress on Acoustics organised by the Institute of Acoustics and the Institute of Physics was held at Imperial College, London from 24 - 31 July 1974. At the request of the organisers AUWE was represented at the associated and co-located Exhibition by D. Gawler, R. Dawe and A. Lanham of the Sonar Department with an exhibit derived from the Establishment's open week items covering "The Historical Development of Sonar", "Transducer Elements and Arrays" and "Beamforming".

Mr. Stephen Bragg, Vice Chancellor of Brunel University officially opened the Exhibition and in visiting the AUWE stand was interested to find in the Historical section, 1916 vintage hydrophones with which the name of his grandfather, Prof. W. H. Bragg, is closely associated.

A large proportion of the 1,500 participants in the Congress visited the AUWE exhibition, many showing keen interest particularly in the

transducer section. Dr. D. H. Parkinson DGERPA made an unexpected visit to the stand accompanied by Dr. Blitz of the Congress organising committee.

CER's Summer Conference was held at AUWE on Friday 17 May and was preceded on the Thursday evening by a dinner at Weymouth Pavilion. The dinner was presided over by Sir George Macfarlane, CER and the guest speaker was Mr. E. C. Cornford, Deputy Chief Executive (PE). The guests included Mr. B. W. Lythall, CS(RN), and Vice Admiral P. A. Watson, Director General Weapons (Navy).

The annual cocktail party given by the Principal Officers Mess was held on conclusion of the Summer Conference, and was attended by over 300 members and guests.

Captain W. E. B. Godsall has been relieved by Captain J. H. St. Aubyn Sayer as Captain Underwater Weapons Acceptance.

Mr. Frank Judd MP, Under Secretary of State for Defence for the Royal Navy paid a brief visit to AUWE during the Open Week. He arrived at Portland by helicopter in the afternoon, toured the exhibits and departed again in the same way for London later in the day.

AUWE had the pleasure of receiving delegates from Australia, Canada, New Zealand, and U.S.A. in June. The occasion was the 21st meeting of TTCP Sub Group G, the body which regulates quinqué partite international collaboration on undersea warfare.

Aside from the formal business the opportunity was taken to show the visitors AUWE's Sonar research facilities in RDV Crystal. Visits were made also to the Plessey Marine Research Unit at Wincanton and to H.M.S. *Matapan*.



Mr. Frank Evans, Principal Scientific Officer at the Admiralty Underwater Weapons Establishment Portland has been appointed Companion to the Imperial Service Order in the recent Queen's Birthday Honours. Thereby he joins a select group of civil servants as the Order consists of the Sovereign and just over 1,000 Companions.

On Wednesday 24 July at an Investiture at Buckingham Palace, he received the Insignia of the Order from Her Majesty the Queen.

Mr. Evans joined Admiralty Service on loan from Ricardo & Co., Research Engineers at Shoreham in 1940 as a Technical Officer. He was established in the service in 1947.

Until 1959 when Mr. Evans was transferred to AUWE Portland, he was mainly employed on a number of underwater weapon projects. In 1949 he represented the Royal Naval Scientific Service carrying out trials on underwater projects during a cruise of Fleet Units in Arctic waters.

Since 1959 Mr. Evans has been mainly concerned with Scientific staff administration and training at AUWE.

Mr. R. Jarvis retired in June 1974 after 34 years of continuous service with the RNSS.

His first contact with the Admiralty came via a stringent security check! He submitted a design for a pressure mine in 1940 when such a subject was Top Secret indeed. The Admiralty decided that such a man was better in the Service, than outside it, and he joined the Degaussing Service as a TEA2 in Hull where he remained until 1945. In that year he transferred to the Admiralty Mining Establishment at Havant where his inventive genius was allowed full play in the design of components to be used in mine circuits. His "piece de resistance" was undoubtedly a Ship Counter

no bigger than a matchbox capable of 50 actuations. Came the "Way Ahead" of 1959/60 and Ron found himself at Portland, now on mine countermeasures perhaps the prime example of "set a thief to catch a thief". From this work came the Recoverable Mine Actuation Recorder for which he received an interim award and a Certificate of Merit. In 1968 he was asked to transfer his attentions to equipment to assist in rendering safe all manner of explosive devices, and after some success came the day of final retirement.



His inventive genius, and indeed his consummate craftsmanship will be missed at AUWE, but undoubtedly fully appreciated by his wife! We wish them both a happy retirement.



Admiralty Surface Weapons Establishment

The end of June 1974 saw the conclusion of the career of one of A.S.W.E's. longest serving officers—**Mr. Norman Vidler**.

After serving his apprenticeship in the Electrical Department of H.M. Dockyard, Portsmouth, and duties in the Drawing Offices of both H.M.S. *Vernon* and H.M. Dockyard, he joined the Experimental Department of the R.N. School in the R.N. Barracks at Portsmouth in May 1939.

With the outbreak of war in September 1939 the activities of Signal School became diversified and Mr. Vidler saw service in outstation departments and Shipyards throughout the country, returning to the new Headquarters of the re-named Admiralty Signals Establishment at Lythe Hill House, Haslemere, Surrey in September 1942 as a Technical Assistant.



Towards the end of 1944 a committee was convened to plan the future A.S.E. and Mr. Vidler became an active participant in this plan. The existing Establishment was at this time spread piecemeal over the whole of the country, and was both complex and unwieldy to administer. After many deliberations, the plan for the Portsdown Site was agreed and Mr. Vidler became deeply involved in planning, progress and priorities of the whole site area. In the summer of 1948, now an Experimental Officer in the R.N.S.S., Mr. Vidler was appointed as Officer-in-Charge at Portsdown to oversee the whole site.

During the ensuing years, Mr. Vidler followed every aspect of the construction of the new Establishment, from buildings, services, accommodation requirements, telephones etc. It was not until 1955 that he saw the new A.S.R.E. as it had been planned. He subsequently followed through two further stages of the A.S.W.E. site development; the "Way Ahead" programme which resulted in the assimilation of A.G.E. and the then A.S.R.E. to form the overall group Admiralty Surface Weapons Establishment, and then the construction of Block 4 which was completed in 1966.

Within the past few years A.S.W.E. has continued to grow and Mr. Vidler has been closely involved in all aspects of the development of Block 5 and Funtington.

He was originally due for retirement in June 1973, but was retained for a further year in order to record the depth of his overall knowledge of A.S.W.E. sites and services.

On his retirement he will have completed almost 45 years' service, and apart from his contribution to the development of the Establishment, he will be remembered by his many friends for his activities in the Sports Club, where he was well known as both cricketer and umpire, and to many of the children of A.S.W.E. staff as "Uncle Norman" at the Children's Annual Christmas Party.



Controlled Release of Antifouling Agents

Naval Ship Research and Development Center (U.S.A.)—One objective of the Navy's R & D effort in pollution abatement is the development of antifouling coatings and antifouling agents possessing minimum pollution hazard with maximum antifouling effectiveness. Because state-of-the-art antifouling technology has not provided a means of controlling the leaching rate of toxic coating components into the marine and freshwater environments, the Naval Ship Research and Development Center introduced the idea of chemically binding organo-metallic compounds on polymer backbones to reduce the ecological impact of these pesticides in the aqueous environment. This effort involves the synthesis of antifouling organometallic polymers (AMPs) of tributyltin, tripropyltin, tribenzyltin, triphenyltin, trimethyltin and triphenyllead moieties chemically bonded to acrylic vinyl, polyester, epoxy and polyurethane resins. Various OMP coating formulations and fibre reinforced OMP composites applied to test panels are under exposure in Hawaii, Florida, and the Center's Annapolis, Maryland, site. They have continued to exhibit excellent antifouling performance after 28 months of immersion.

A two-part test methodology developed at the Annapolis Laboratory provides quantitative data on the ecological impact of these and other antifouling agents. (1) A rotating cylinder apparatus simulates ships' hull behaviour and dynamically ages the antifouling materials under test. (2) Using seven Chesapeake Bay organisms, an LD 50 is determined under controlled Laboratory conditions for inorganic copper salts, organometallic salts and OMP's. Utilizing these test data OMP's are chemically modified to reduce leaching rates to a minimum while maintaining long-term antifouling effectiveness.

New Ocean Survey Ship joins the Royal Navy

H.M.S. *Herald*, a new ocean survey ship, has been accepted into the Royal Navy from Robb Caledon Shipbuilders Ltd. The handing over took place at sea in the Firth of Forth after the successful completion of acceptance trials.

She is the fourth ship of her class in the Navy's Surveying Service—the others, *Hecla*, *Hecate* and *Hydra* having been built in 1965. *Herald* incorporates a number of improvements resulting from the operational experiences of these ships.

Capable of carrying out hydrographic and oceanographic surveys anywhere in the world, she is 260ft. long and displaces 2,945 tons. Her equipment includes a computerised data-logging system, a satellite navigator, gravity meter, magnetometer, sonars, echo-sounders, coring and oceanographic winches, and two surveying motor boats for close inshore work.

She also carries a Wasp helicopter for aerial photography in connection with survey tasks, as well as for carrying stores and men.

H.M.S. *Herald's* propulsion is diesel-electric single-screw, with a transverse bow thrust propeller to aid manoeuvrability. Her maximum speed is 14 knots and she has an endurance of 12,000 miles at 11 knots.

Accommodation for her 128 officers and men is of high standard. Officers and senior ratings have either single or double cabins, and junior ratings a large dining and recreation hall, with separate sleeping accommodation. The ship is air-conditioned throughout and is fitted with a passive stabilisation tank.



BOOK REVIEW

Perception and Performance Underwater. By J. A. Adolfson and T. E. Berghage, John Wiley and Sons, 1974, price £10.60.

Throughout the history of diving there has been almost a complete lack of interest in the relationship of the diver, his equipment, and his performance. Diving equipment was designed to ensure a supply of breathing gas with little or no regard to ease of working within it. If tools were good enough for the job on land they were good enough for the job in the water. It was assumed that underwater work took longer than similar work on dry land but no analyses were ever done to pinpoint the reasons why. Divers did the jobs

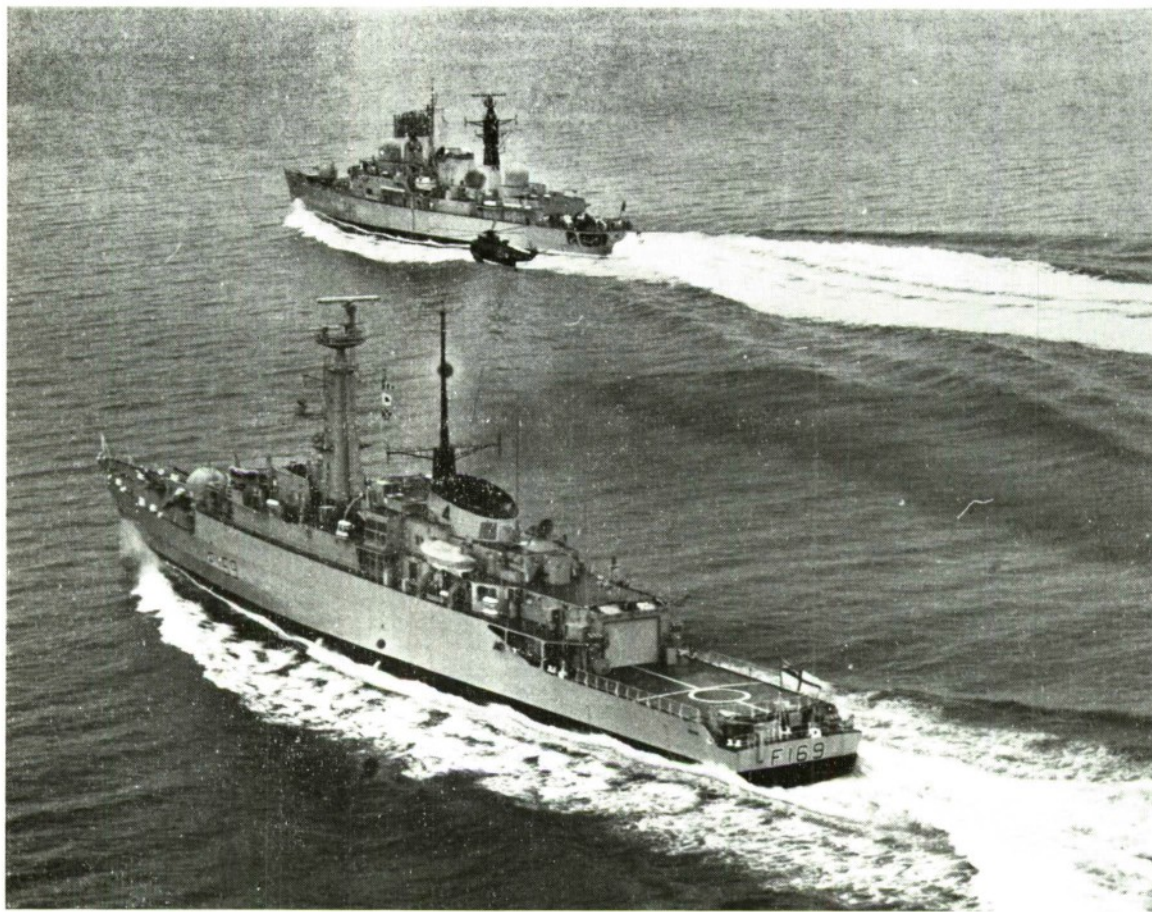
with the available equipment and there developed the attitude of "can do", i.e., regardless of the conditions and equipment the job got completed. The last 15 years have seen a large increase in the numbers and complexity of jobs divers are required to do as well as the depth at which they must work and this old attitude should no longer exist, although regrettably it still does. Perhaps one of the reasons is, that even though a large body of knowledge about diver performance has been built up in the same period of time it has been widely scattered throughout the literature of various disciplines. This has made it difficult for those outside this field to find the information they need, or indeed even know of its existence. This problem is now solved as the pertinent information has been gathered together in this volume.

The organisation of the text is logical and makes it very easy to find the information. The first chapter is devoted to an overview of all the factors which can affect diver performance. These include the physical properties of the water environment, physiologic problems directly related to diving, and life support and diving systems. A separate chapter is devoted to each of the major senses that are valuable to a diver and include vision, hearing, spatial orientation, and the chemical and somesthetic senses and effects of cold. Communications takes a large chapter and covers all forms from tactile to electronic helium voice scramblers. The last chapter discusses performance underwater in general and includes an extensive section on different methods of testing that have proven the most valuable for investigating the various parameters of performance. Each chapter is further divided into sections which describe wet and dry, laboratory and field studies. All the investigations cited include the methodology employed so that results can be evaluated on this basis. A short summary of the salient points is included at the end of each chapter. There is a good general index and a bibliography common to this type of textbook; in addition an author index and glossary should prove helpful features.

The authors, both of whom are highly qualified by their own work in this field, have done an excellent piece of work. It should remain the basic reference text in underwater performance for a long time.

J. Vorosmarti
Cdr., M.C., U.S.N.

TWO OF THE NAVY'S NEW WARSHIPS MEET AT SEA FOR THE FIRST TIME



H.M.S. *Amazon* (in the foreground) leader of the new Type 21 frigates, and H.M.S. *Sheffield*, first of the new Type 42 guided missile destroyers photographed from a Sea King helicopter of 819 Naval Air Squadron based at Prestwick south of the Isle of Arran.



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Date of Search: 15 February 2007

Record Summary:

Title: Journal of the Royal Naval Scientific Service
Covering dates 1974 Sep 01 - 1974 Sep 30
Availability Open Document, Open Description, Normal Closure before FOI
Act: 30 years
Held by The National Archives, Kew

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